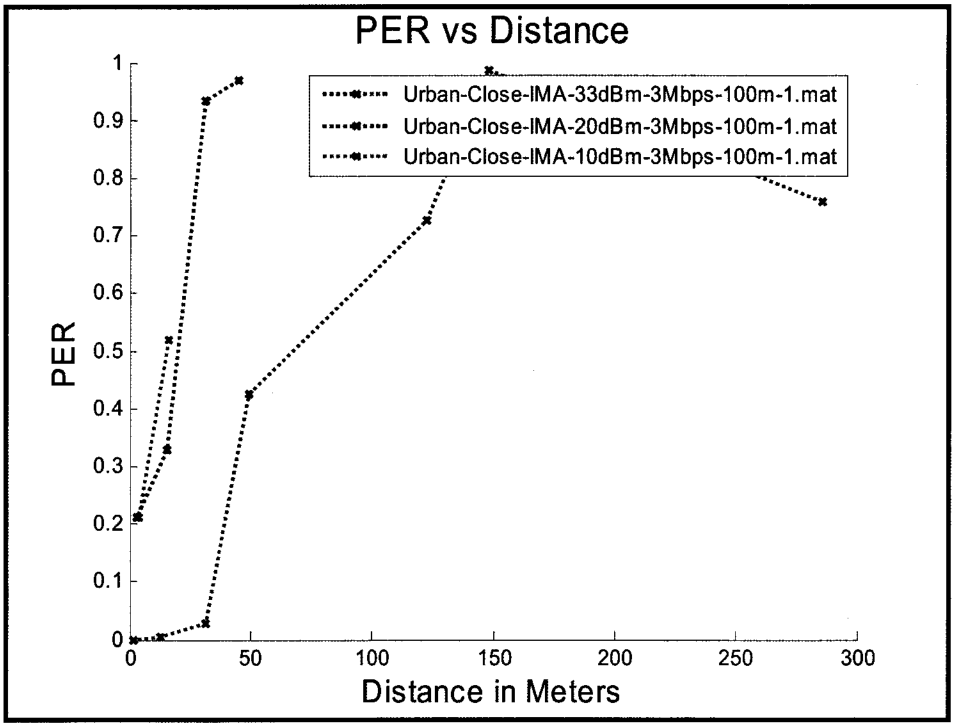


**Figure 26: Comparison of PER versus Distance Curves for Various Power Levels when the Transmitter was 100 Meters from the Intersection and Set to Transmit at 3 Mbps**

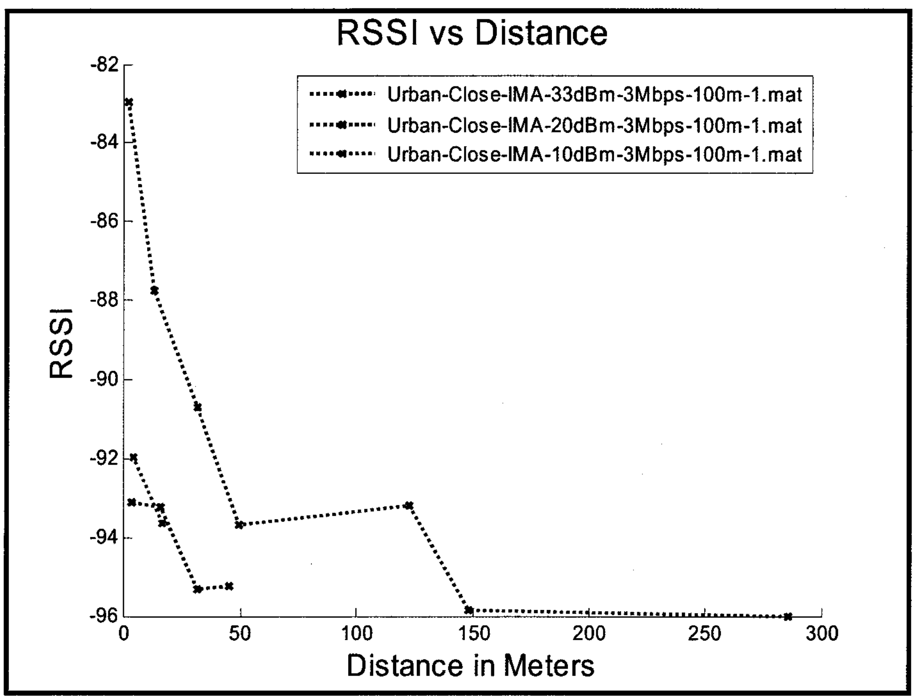


**Figure 27: Comparison of RSSI versus Distance Curves for Various Power Levels when the Transmitter was 100 Meters from the Intersection and Set to Transmit at 3 Mbps**

Figure 28 and Figure 29 show the effect of different data rates (3 Mbps and 6 Mbps) at different transmit powers (20 dBm and 33 dBm). It is apparent that lower rates offer marginally improved performance.

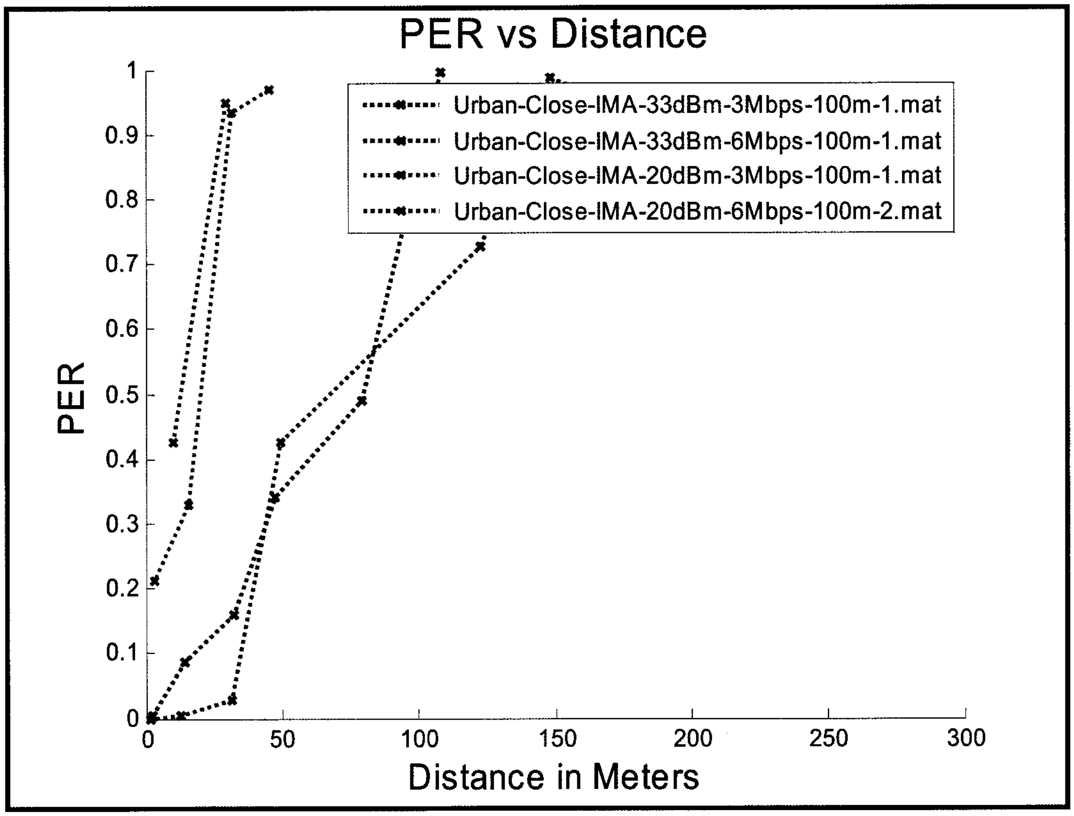


**Figure 28: PER Curves in Urban-Closed-Intersection Scenario for 20 dBm and 33 dBm at 3 Mbps and 6 Mbps**

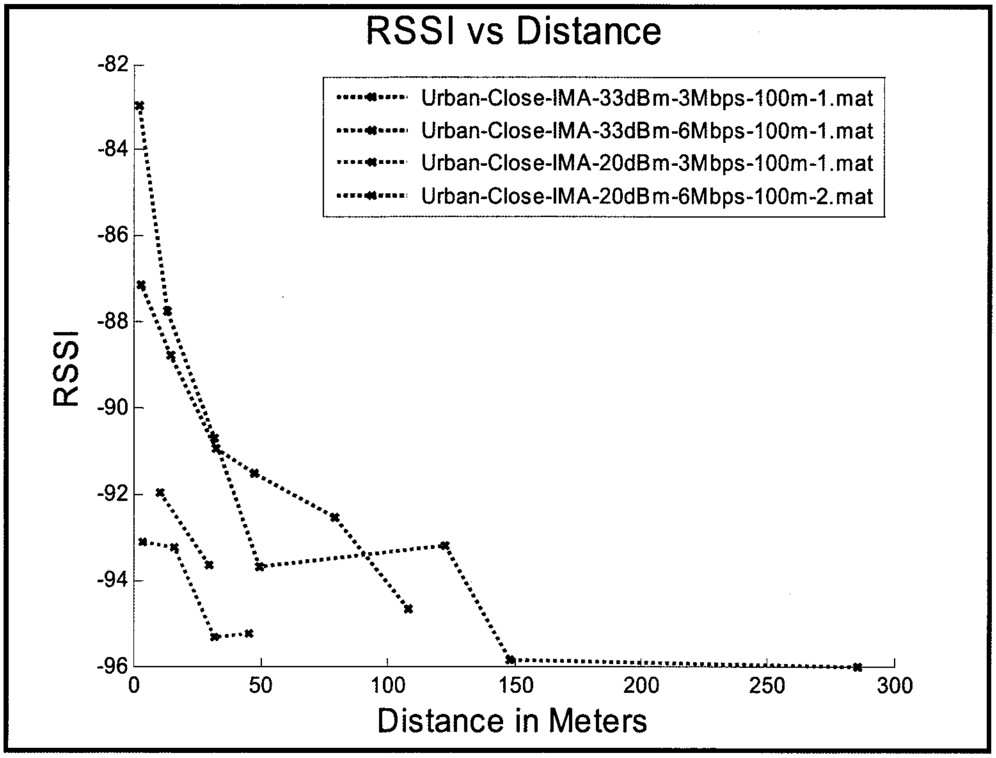


**Figure 29: RSSI Curves in Urban-Closed-Intersection Scenario for 20 dBm and 33 dBm at 3 Mbps and 6 Mbps**

## 8.3 Observations for Urban-Closed-Intersection Scenario

The following observations can be drawn with regard to communication performance in an Urban-Closed-Intersection Scenario.

1. Use of lower powers (20 dBm or lower) offered limited communication range around NLOS corners
2. At the highest permissible power level (33 dBm) and when the transmitter was 150 meters from the intersection, the receiver began to receive packets when it also was about 150 meters from the intersection, though the reception did not become dependable until the receiver was about 75 meters from the intersection.
3. By contrast, when a transmitter 150 meters from the intersection used 20 dBm transmission power, the receiver only began to receive packets when it was about 20 meters from the intersection. Reception did not reach a low PER value until the receiver physically reached the intersection.
4. It is interesting to note that the test case where the transmitter was at 100 meters consistently performed worse than the 150 meters case. Similarly, the results when the transmitter was 0 meters from the intersection consistently performed worse than the 25 meter case. These anomalies were consistent for both the 20 dBm and 33 dBm cases. There are a variety of possible explanations for this deviation from expected trends, including reflections from the buildings, building height, and traffic.

# 9 Urban-¾-Open–Intersection Scenario Test

The Urban-¾-Open-Intersection Scenario test was conducted in downtown San Jose, California, on the corner of Santa Clara and 4th Street. The intersection is categorized as ¾ open because of relatively open spaces on 3 out of the 4 corners. The transmitter-to-intersection distance was set at 4 fixed points (0 meters, 25 meters, 60 meters, and 100 meters), while the receiver drove toward the intersection on Santa Clara Street at the speed of traffic. The test cases outlined in Table 5 were repeated twice for each of the transmitter positions.

**Table 5: Test Cases for the Urban-¾-Open-Intersection Scenario Test**

| TX Power / Data Rate | 10dBm | 20dBm | 26dBm | 33dBm |
|---|---|---|---|---|
| 3Mbps | Test 1 | Test 3 | Test 5 | Test 7 |
| 6Mbps | Test 2 | Test 4 | Test 6 | Test 8 |

## 9.1 Location Overview

Figure 30 and Figure 31 show the intersection at ground level. Figure 30 shows one of the three "open" corners, the southeast, which is a plaza. Figure 31 shows the building on the southwest corner that constituted the principle NLOS obstruction between the transmitter (south of the intersection) and receiver (approaching from the west). The urban, propagation environment exhibited similarities with the Urban-Straight-Line Scenario test and the Urban-Closed-Intersection Scenario test (i.e., reflections from similar buildings, pavement, and vehicles, though clearly this test had a unique topology).

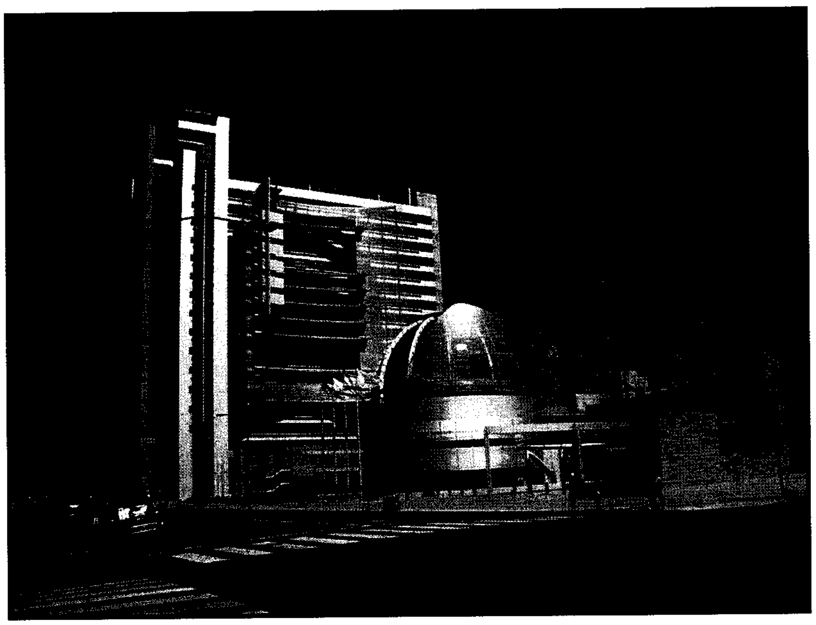

**Figure 30: One Open Corner of the 4th Street and Santa Clara Street Intersection**

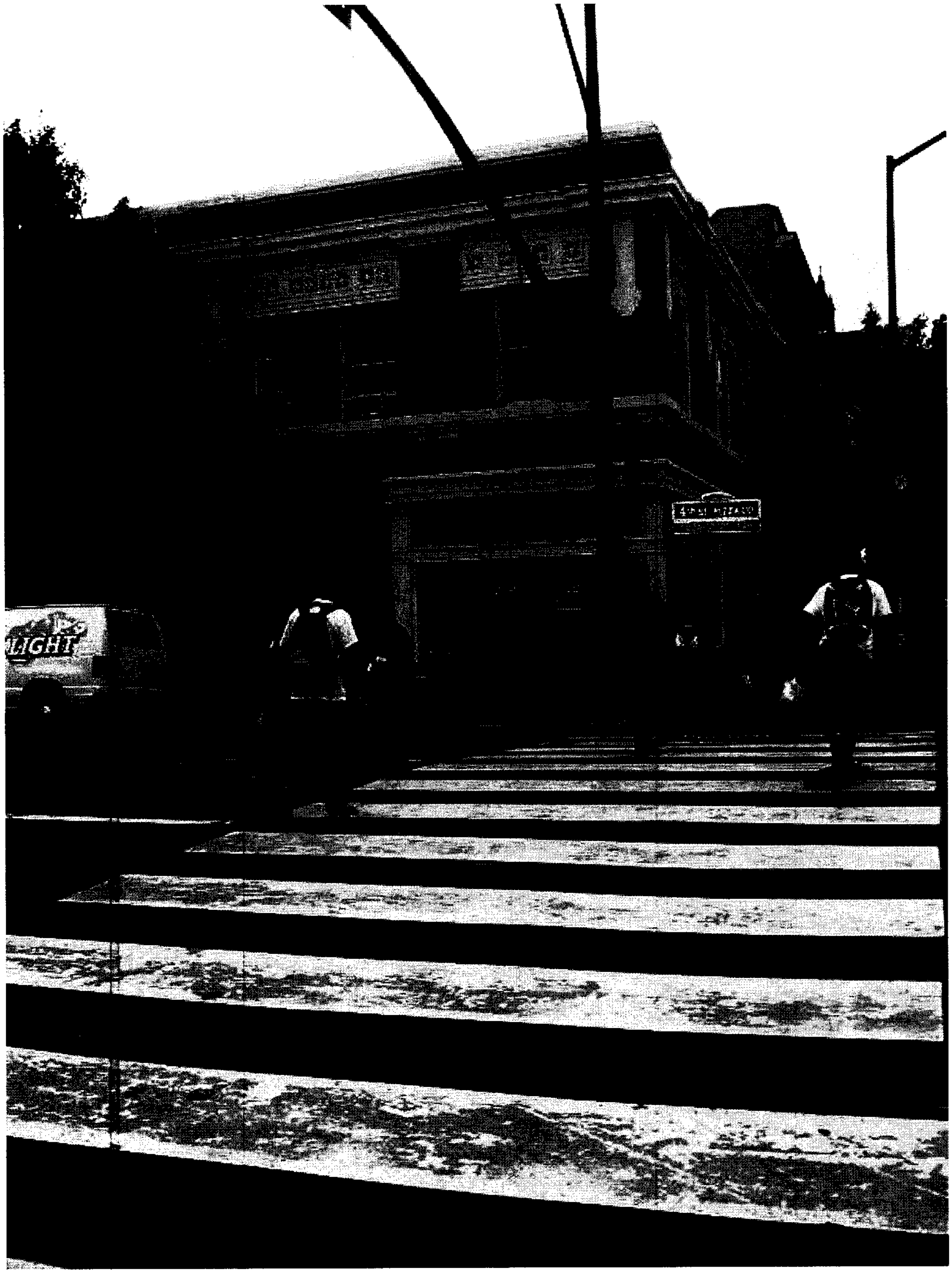


**Figure 31: Closed Corner of the 4th Street and Santa Clara Street Intersection**

## 9.2 Data Analysis

Figure 32 and Figure 33 show PER and RSSI versus distance curves for 33 dBm transmissions at various transmitter locations. It can be seen that as the transmitter moves away from the intersection, communication performance worsens, with the largest degradation occurring between 25 meter and 60 meter transmitter locations.

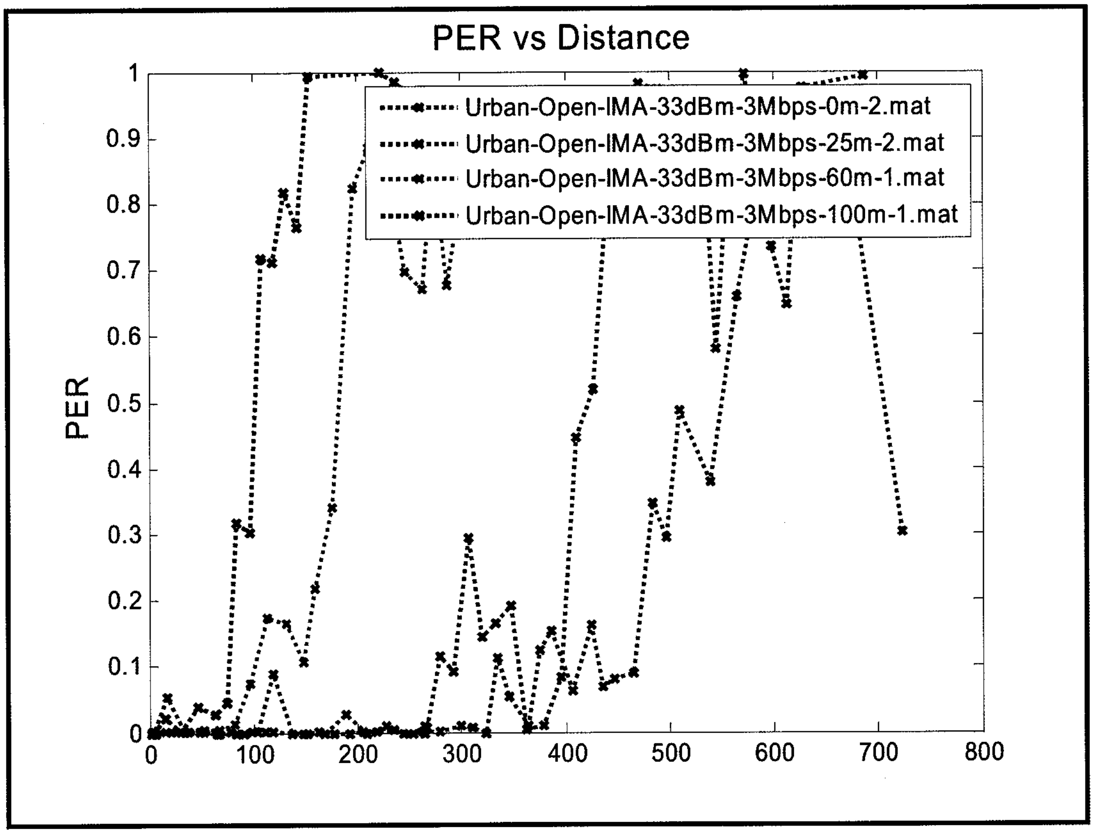


**Figure 32: PER versus Distance Curve at 33 dBm and 3 Mbps for all the Different Transmitter Positions**

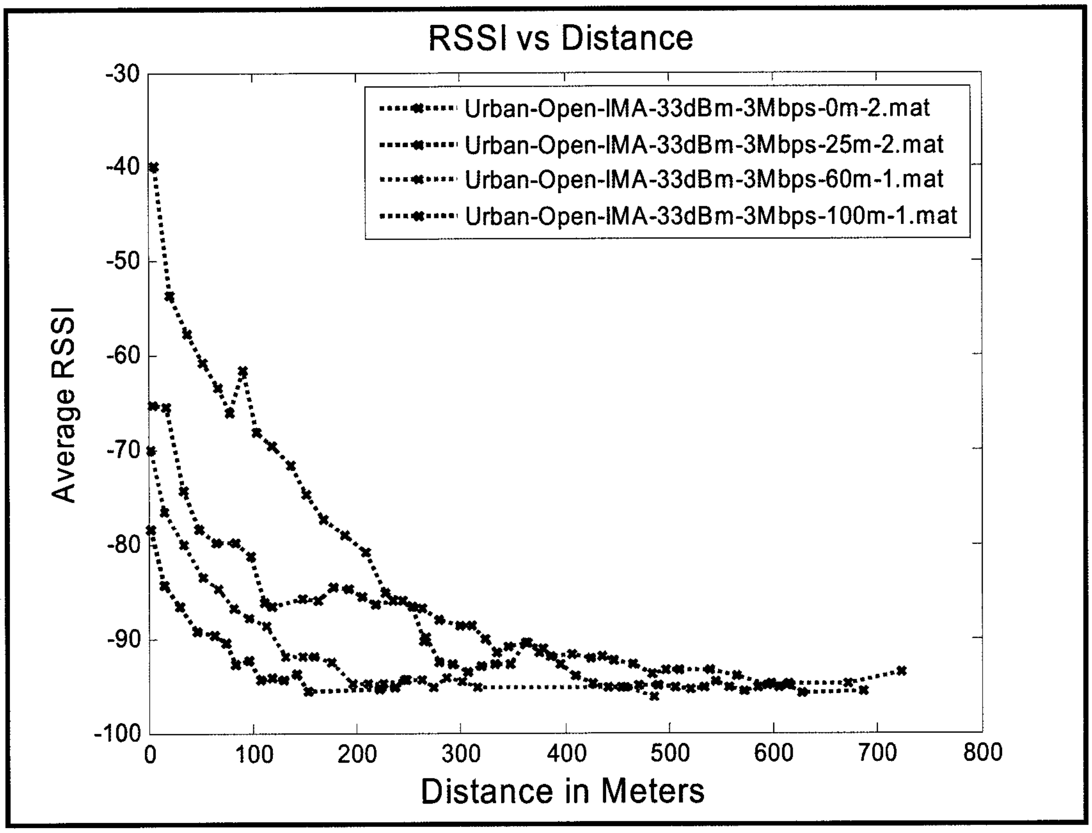


**Figure 33: RSSI versus Distance Curve at 33 dBm and 3 Mbps for all the Different Transmitter Positions**

Figure 34 and Figure 35 show the relationship between communication performance at 3 different power levels (20 dBm, 26 dBm, and 33 dBm) for the specific case where the transmitter was 100 meters from the intersection.

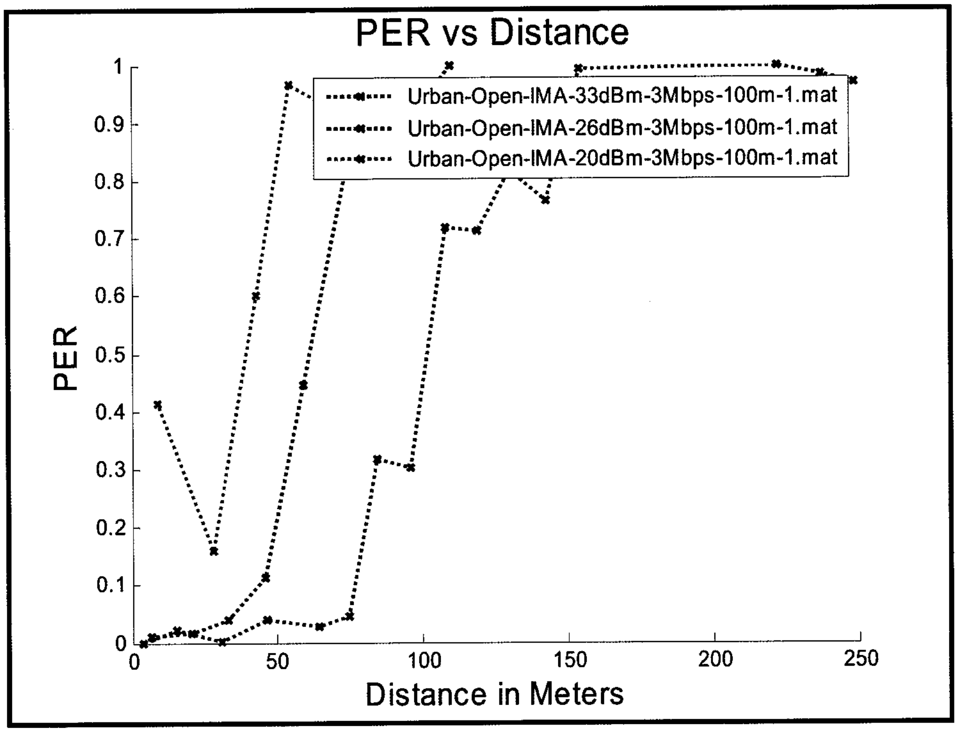


**Figure 34: Comparison of PER versus Distance Curves for Various Power Levels when the Transmitter was 100 Meters from the Intersection and Set to Transmit at 3 Mbps**

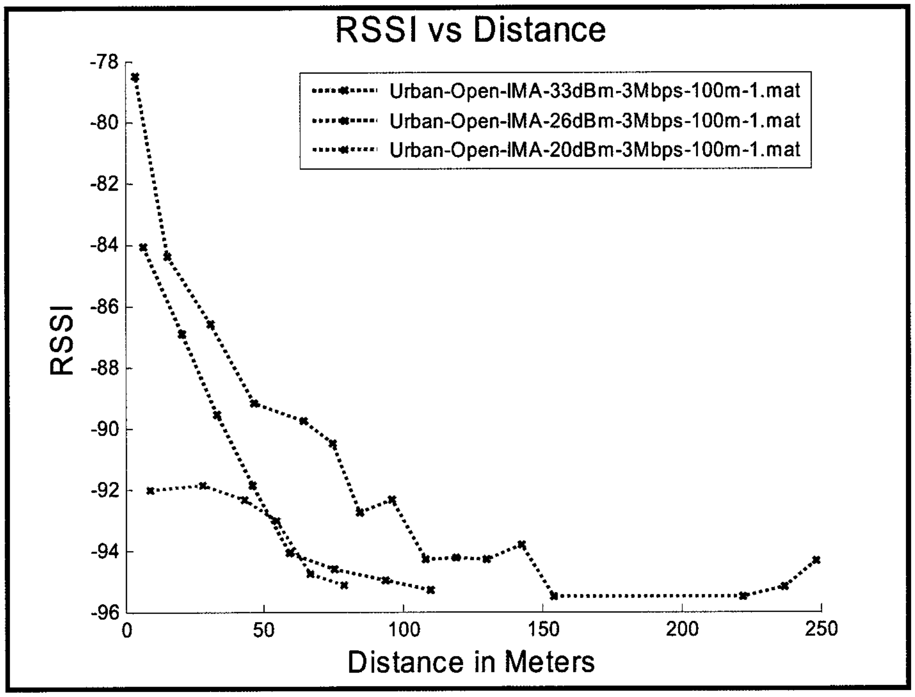


**Figure 35: Comparison of RSSI versus Distance Curves for Various Power Levels when the Transmitter was 100 Meters from the Intersection and Set to Transmit at 3 Mbps**

Figure 36 and Figure 37 show the effect of different data rates (3 Mbps and 6 Mbps) at different transmit powers (20 dBm and 33 dBm).

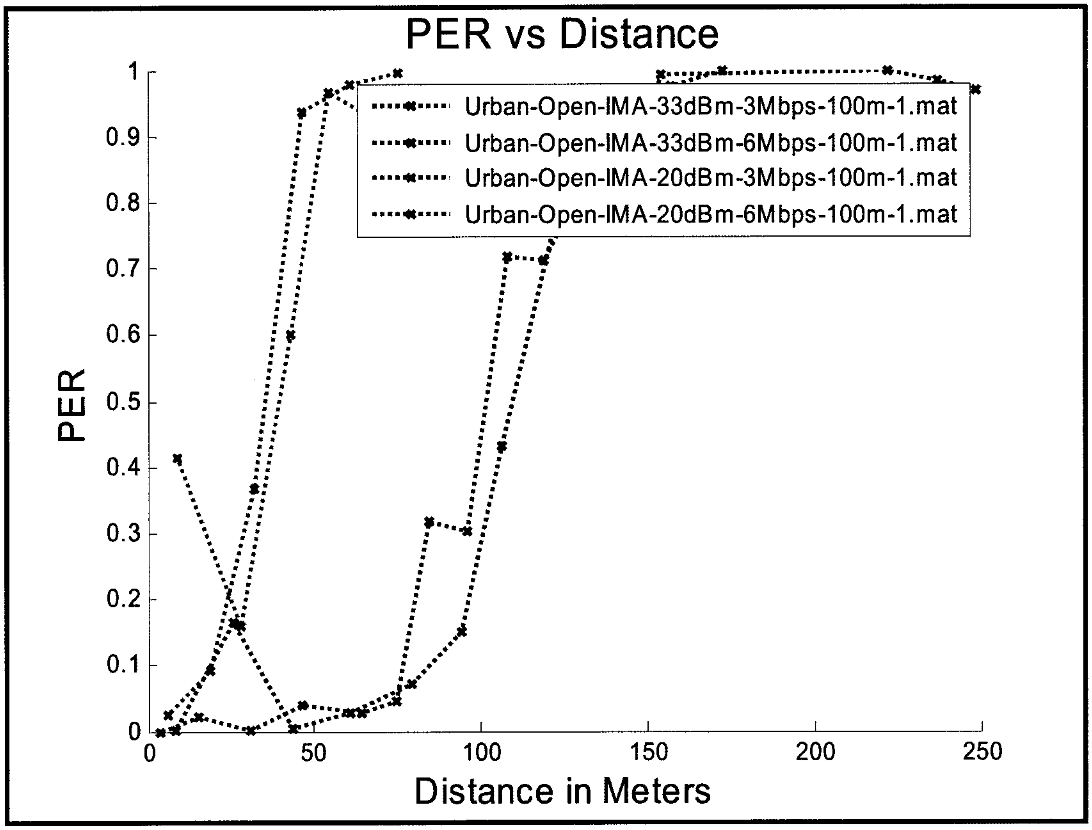


**Figure 36: Comparison of PER versus Distance Curves in Urban-Open-Intersection at 33 dBm and 20 dBm for 3 Mbps and 6 Mbps**

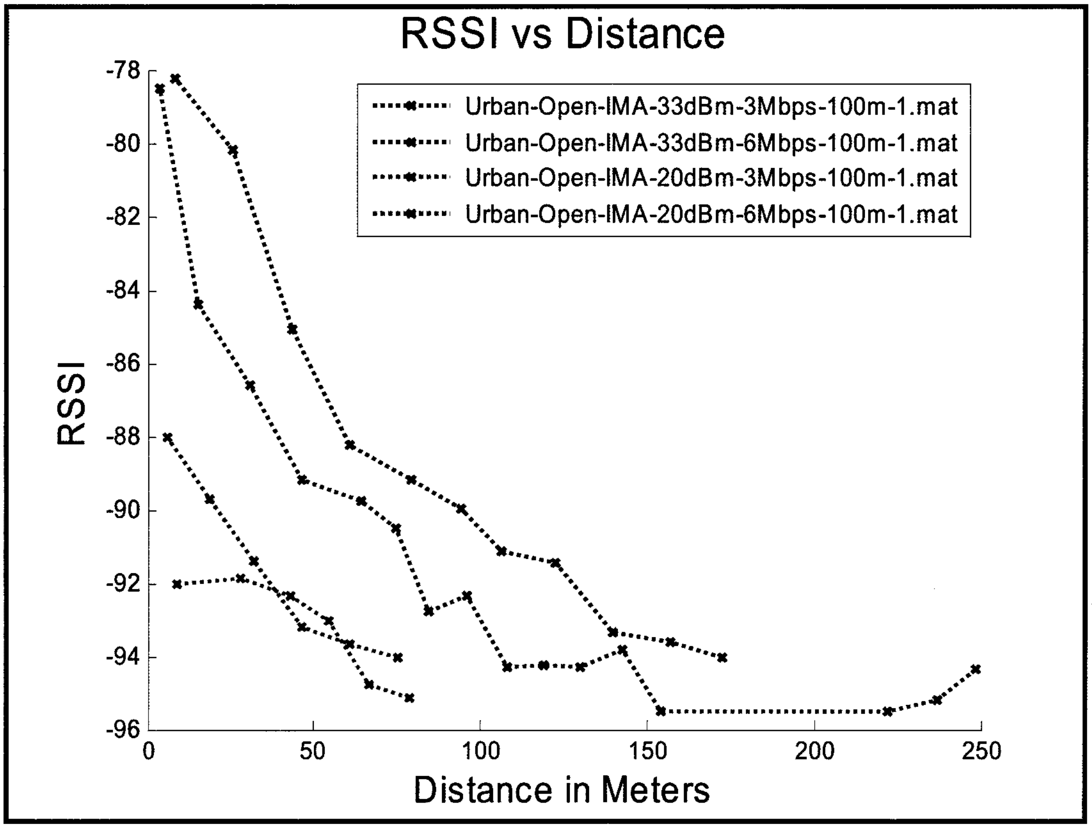


**Figure 37: Comparison of RSSI versus Distance Curves in Urban-Open-Intersection at 33 dBm and 20 dBm for 3 Mbps and 6 Mbps**

## 9.3 Observations for Urban-¾-Open-Intersection Scenario

The following observations can be drawn with regard to communication performance in a ¾-Open-Urban-Intersection Scenario:

1. Use of lower powers (20 dBm or lower) offered limited communication range around NLOS corners. In particular, Figure 36 shows that when the transmitter was 100 meters from the intersection, a 20 dBm transmission could not be heard at all by a receiver more than approximately 50 meters from the intersection, and could not be heard reliably (< 10 percent PER) until the receiver was within a few meters of the intersection.
2. At the highest permissible power level (33 dBm), a transmitter 100 meters from the intersection began to be heard by a receiver about 250 meters from the intersection and reliable communication (PER < 10 percent) began at about 75 meters
3. The lower 3 Mbps bit rate does not offer any appreciable advantage compared to the 6 Mbps bit rate

## 9.4 Comparison of Urban-Closed-Intersection and Urban-¾-Open-Intersection Scenarios

Figure 38 and Figure 39 offer a comparison between the Urban-Closed-Intersection Scenario (3 runs) and Urban-¾-Open-Intersection Scenario tests (2 runs) in an urban setting. Only one transmitter location (100 meters) is used for the comparison. It is interesting to note that the Open Intersection case resulted in more reliable communications, extending the range where the receiver experiences 10 percent PER or less from about 40 meters to about 80 meters. This is consistent with a view that the closed intersection's additional reflection points create a more challenging multi-path environment, but it is contrary to an opposing view that the lack of an obvious reflection point makes the Urban-¾-OpenIntersection Scenario test case more difficult.

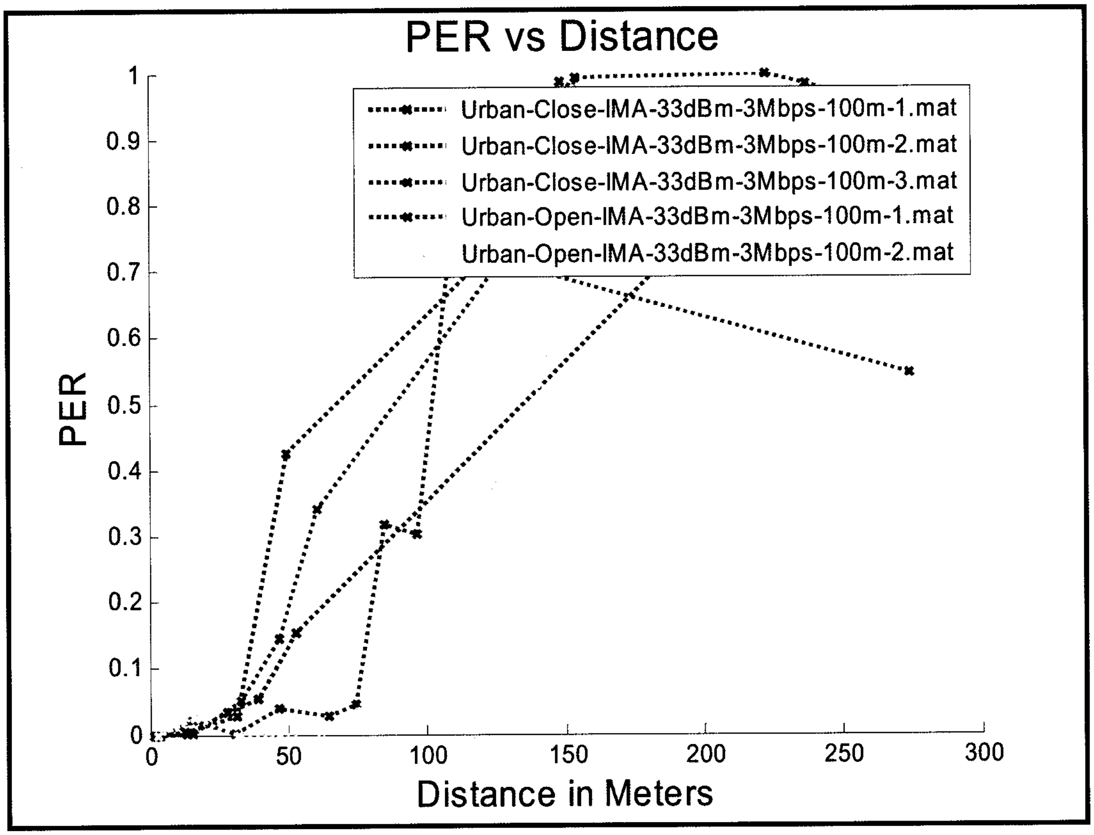


**Figure 38: PER Comparison of Urban-Closed-Intersection Scenario and Urban-Open-Intersection Scenario for 33 dBm at 3 Mbps**

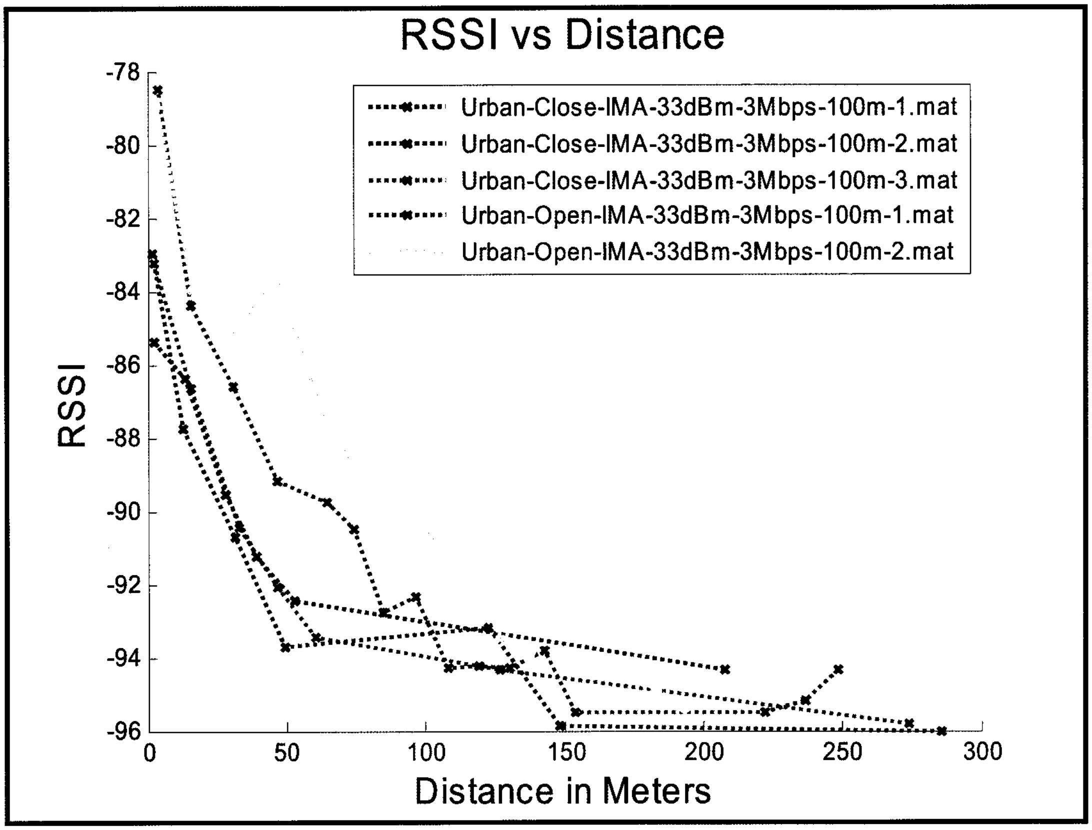


**Figure 39: RSSI Comparison of Urban-Closed-Intersection Scenario and Urban-Open-Intersection Scenario for 33 dBm at 3 Mbps**

# 10 Suburban-Closed-Intersection Scenario Test

The Suburban-Closed–Intersection Scenario test was conducted in Palo Alto, California, on the corner of Santa Rita Avenue and Byron Street. The test is categorized as a closed-intersection test because of the presence of homes on all four corners of the intersection. The transmitter-to-intersection distance was set at 3 fixed points (0 meters, 50 meters, and 100 meters), while the receiver drove toward the intersection at a speed of 5 mph. The test cases outlined in Table 6 were repeated for each of the transmitter positions.

**Table 6: Test Cases for Suburban-Closed-Intersection Scenario**

| Data Rate \ TX Power | 10dBm | 20dBm | 26dBm | 33dBm |
|---|---|---|---|---|
| 3Mbps | Test 1 | Test 3 | Test 5 | Test 7 |
| 6Mbps | Test 2 | Test 4 | Test 6 | Test 8 |

## 10.1 Location Overview

Figure 40 and Figure 41 show the propagation environment for the Suburban-Closed-Intersection Scenario. The corner of Santa Rita and Byron is fairly representative of a typical suburban environment with a lining of trees and single story homes on both sides of the street.

The home on the west corner of the intersection (Figure 40) served as the primary LOS obstruction between the two vehicles.

**Figure 40: West Corner of Santa Rita Avenue and Byron Street**

Figure 41 gives an idea of the propagation environment as the receiver drove northeast on Santa Rita Avenue toward the intersection[2].

**Figure 41: Propagation Environment along Santa Rita Avenue**

[2] The photo in Figure 41 was not taken on the day of testing; the parked vehicles shown were not present.

## 10.2 Data Analysis

Figure 42 and Figure 43 show PER and RSSI versus distance curves for a 33 dBm transmission at various transmitter locations. It can be seen that communication performance worsens as the transmitter moves away from the intersection.

Figure 44 and Figure 45 show the relationship between communication performance at two different power levels (20 dBm and 33 dBm).

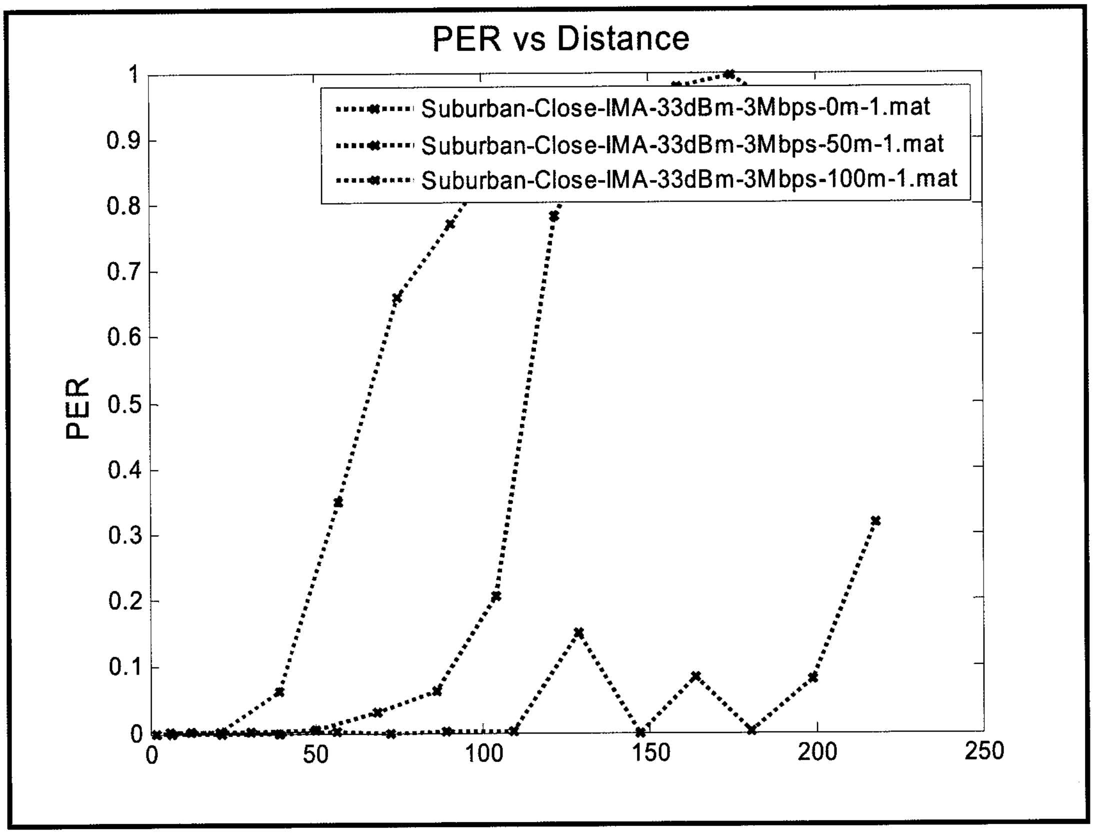


**Figure 42: PER versus Distance Curves for Various Transmitter Locations at 33 dBm and 3 Mbps**

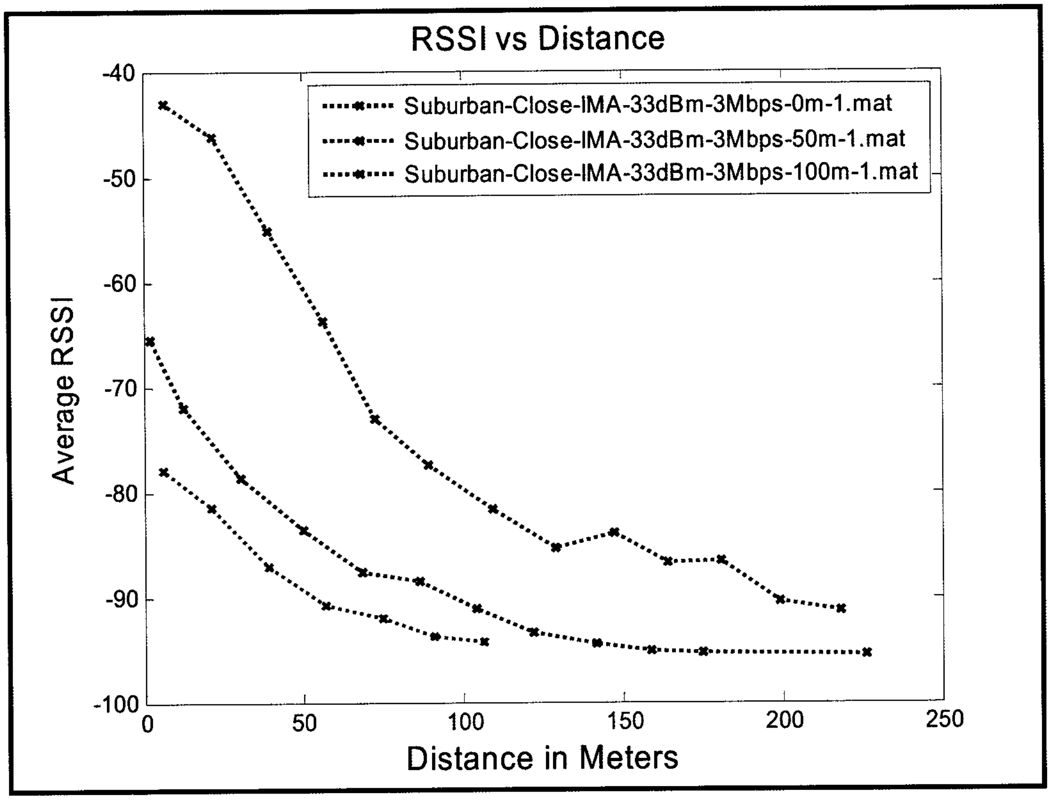


**Figure 43: RSSI versus Distance Curves for Various Transmitter Locations at 33 dBm and 3 Mbps**

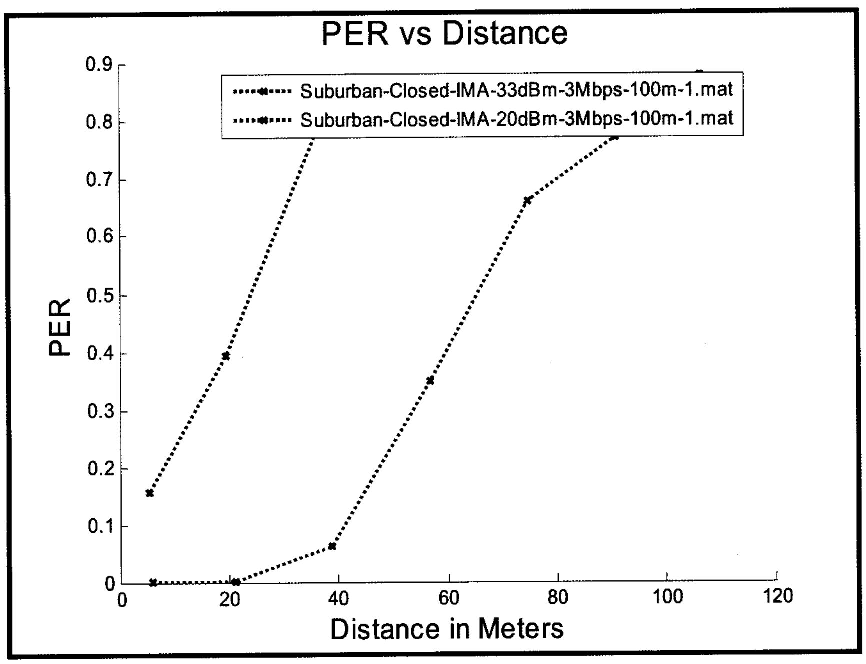


**Figure 44: Comparison of PER versus Distance Curves between 20 dBm and 33 dBm when the Transmitter was 100 Meters from the Intersection and Set to Transmit at 3 Mbps**

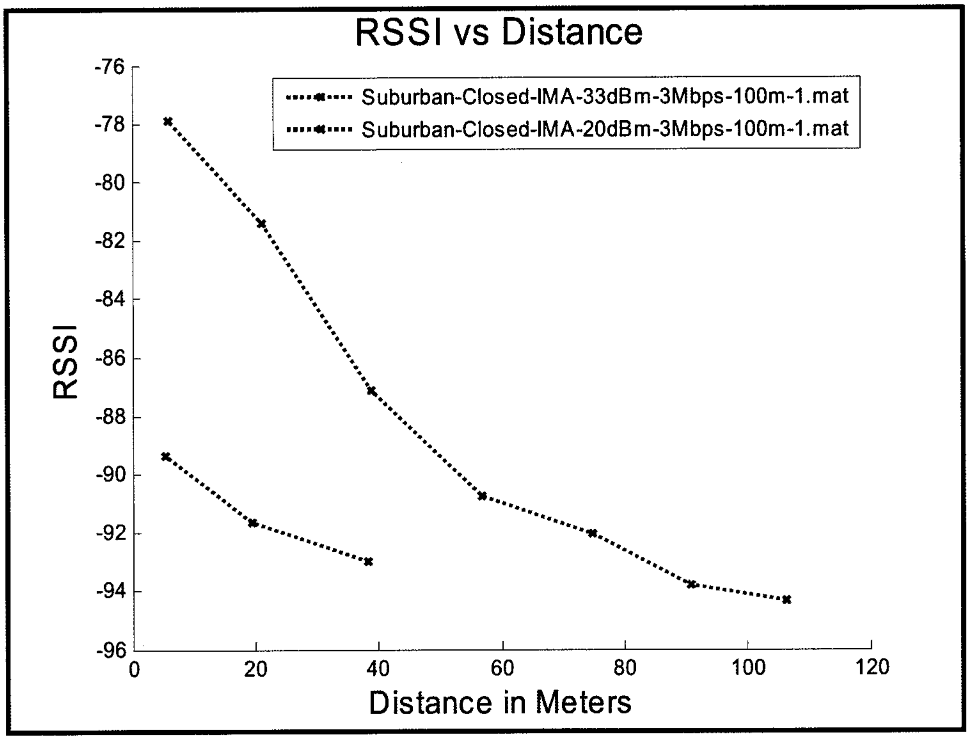


**Figure 45: Comparison of RSSI versus Distance Curves between 20 dBm and 33 dBm when the Transmitter as 100 Meters from the Intersection and Set to Transmit at 3 Mbps**

Figure 46 and Figure 47 show the effect of different data rates (3 Mbps and 6 Mbps) at different transmit powers (20 dBm and 33 dBm) for the specific case where the transmitter was 50 meters from the intersection.

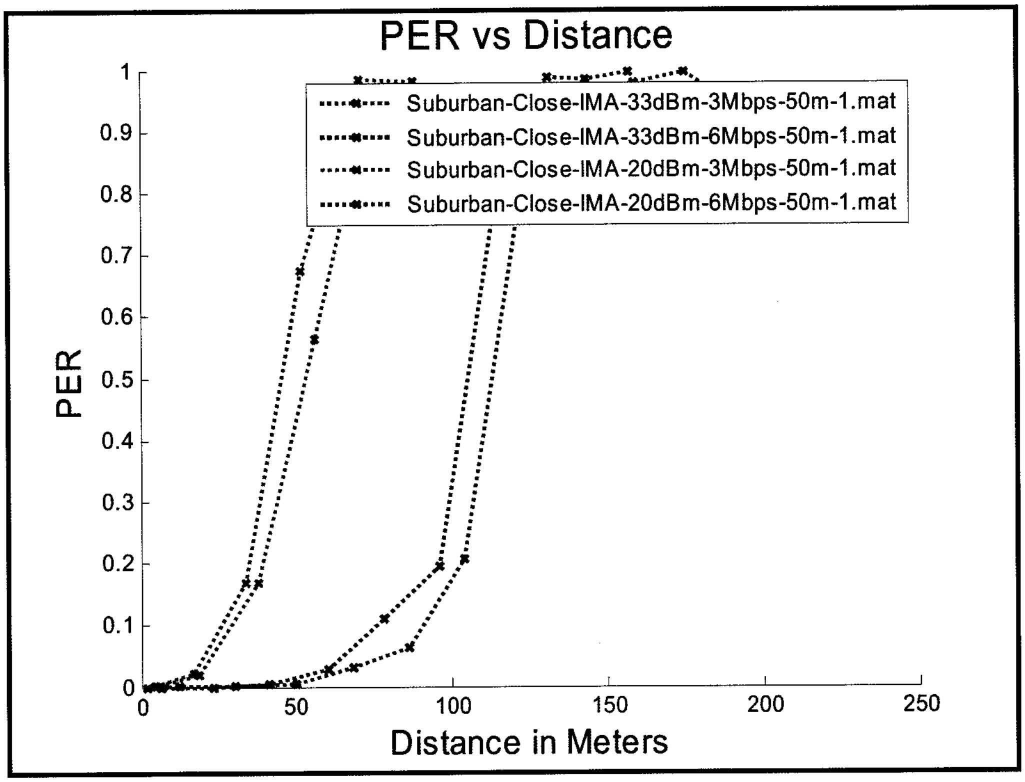


**Figure 46: PER Comparison for Suburban-Closed-Intersection Scenario for 33 dBm and 20 dBm at 3 Mbps and 6 Mbps**

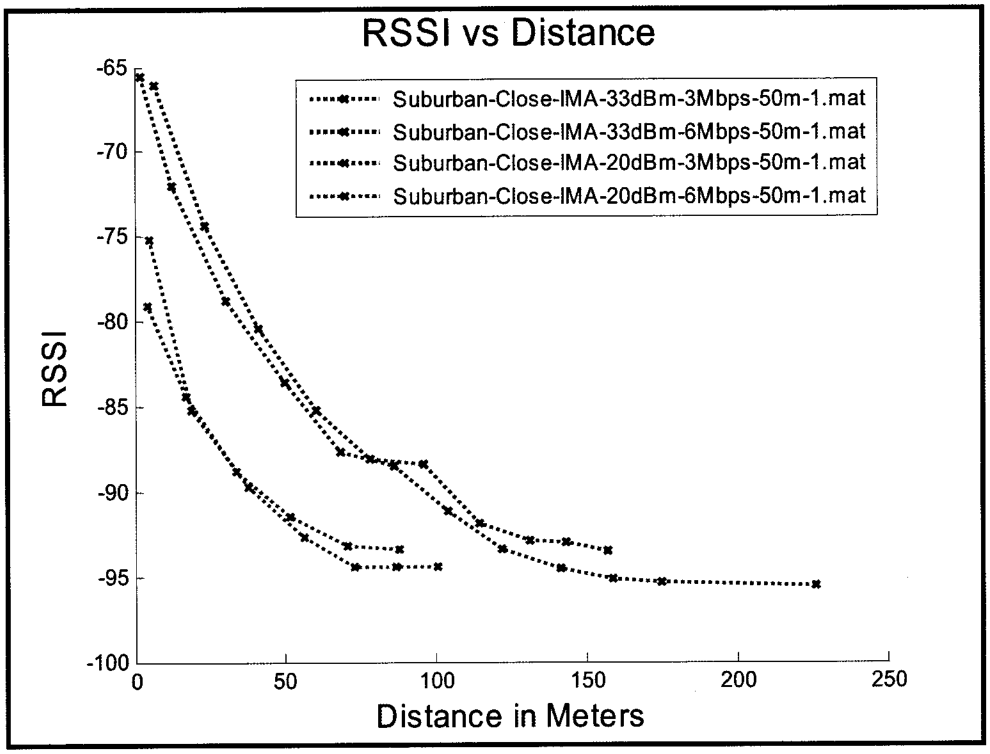


**Figure 47: RSSI Comparison for Suburban-Closed-Intersection Scenario for 33 dBm and 20 dBm at 3 Mbps and 6 Mbps**

## 10.3 Observations for Suburban-Closed-Intersection Scenario

The following observations can be drawn with regard to communication performance in a Suburban-Closed-Intersection Scenario:

1. Use of lower powers (20 dBm or lower) offered limited communication range around NLOS corners. In particular, when the transmitter was 100 meters from the intersection, the receiver was not able to achieve a PER lower than 15 percent. When the transmitter was 50 meters from the intersection, the receiver achieved a low PER (< 10 percent) when it was about 25 meters from the intersection. See Figure 44 and Figure 46.
2. By contrast, when the transmitter was set to 33 dBm and was 100 meters from the intersection, the receiver began decoding packets reliably (PER < 10 percent) at about 40 meters from the intersection. When the transmitter was 50 meters from the intersection, reliable reception began at about 80 meters. See Figure 42.
3. The lower 3 Mbps bit rate offers a marginal advantage as compared to the 6 Mbps bit rate

# 11 Suburban-¾-Open-Intersection Scenario Test

The Suburban-¾-Open-Intersection Scenario test was conducted in Menlo Park, California, on the corner of Middlefield Road and Willow Road. The intersection is categorized as ¾ open because of relatively open spaces on 3 out of the 4 corners. The transmitter-to-intersection distance was set at 3 fixed points (16 meters, 50 meters, and 80 meters), while the receiver drove toward the intersection at the speed of traffic. The test cases outlined in Table 7 were repeated for each of the transmitter positions.

**Table 7: Test Cases for the Suburban-3/4-Open–Intersection Scenario**

| TX Power / Data Rate | 10dBm | 20dBm | 26dBm | 33dBm |
|---|---|---|---|---|
| 3Mbps | Test 1 | Test 3 | Test 5 | Test 7 |
| 6Mbps | Test 2 | Test 4 | Test 6 | Test 8 |

## 11.1 Location Overview

The east corner of this intersection has a one-story office building with trees while the other three corners have lawns or parking with setback buildings. The building on the east corner served as the obstruction between the two vehicles.

## 11.2 Data Analysis

Figure 48 and Figure 49 show PER and RSSI versus distance curves for 33 dBm transmissions at various transmitter locations. It can be seen that when the transmitter was 16 meters from the intersection, transmitter performance was better than when it moved farther away. Also, there was little difference in performance between the 50 meter and 85 meter transmitter locations.

Figure 50 and Figure 51 show the relationship between communication performance at 3 different power levels (20 dBm, 26 dBm, and 33 dBm).

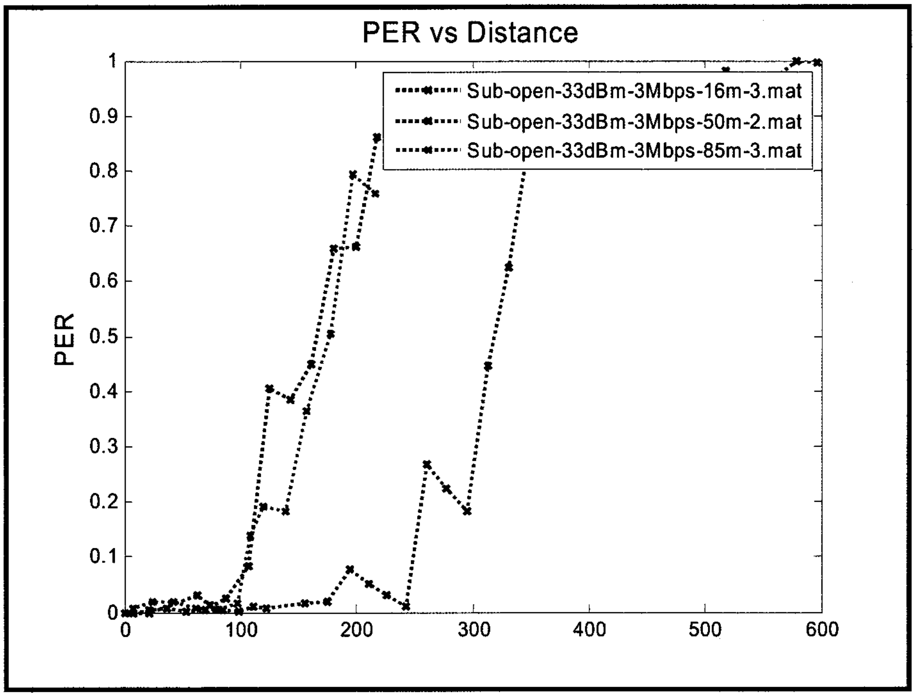


**Figure 48: PER versus Distance Curves for Various Transmitter Locations at 33 dBm and 3 Mbps**

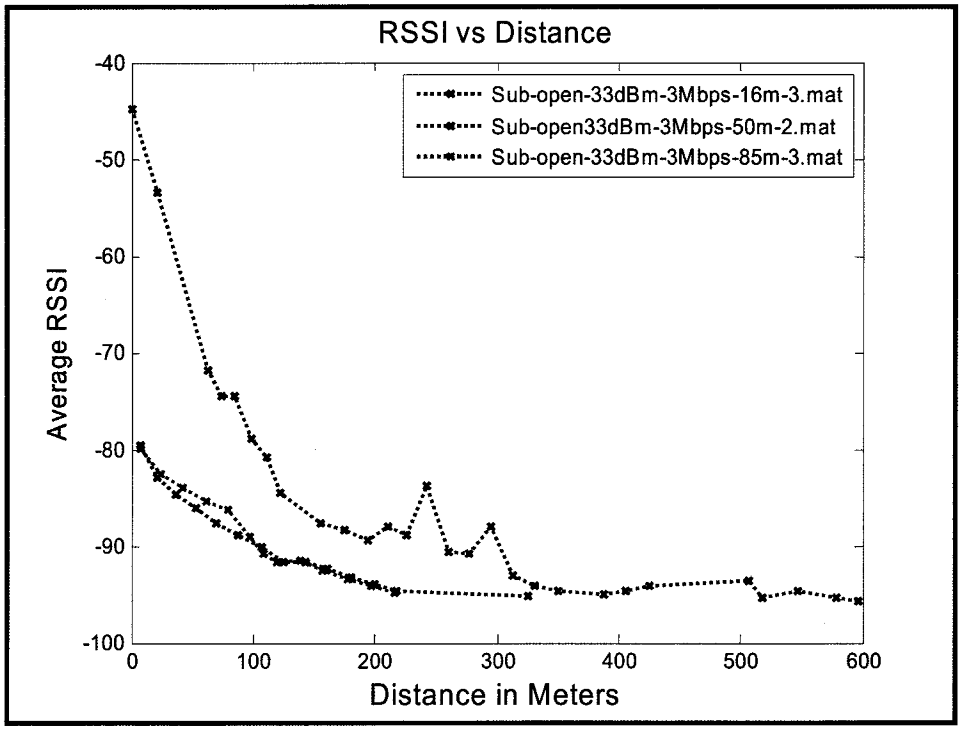


**Figure 49: RSSI versus Distance Curves for Various Transmitter Locations at 33 dBm and 3 Mbps**

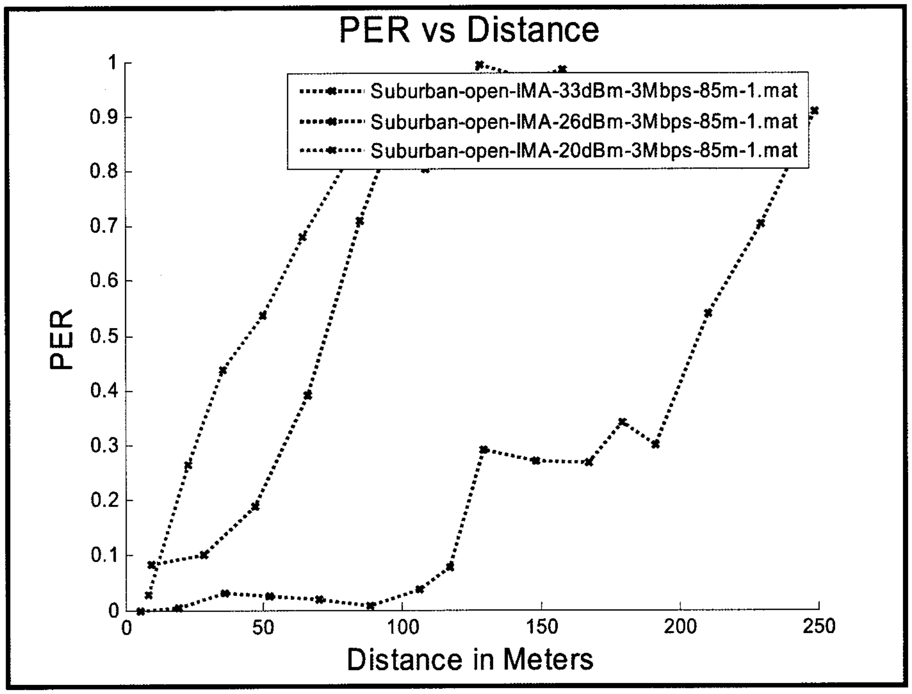


**Figure 50: Comparison of PER versus Distance Curves Between 20 dBm, 26 dBm, and 33 dBm when the Transmitter was 85 Meters from the Intersection and Set to Transmit at 3 Mbps**

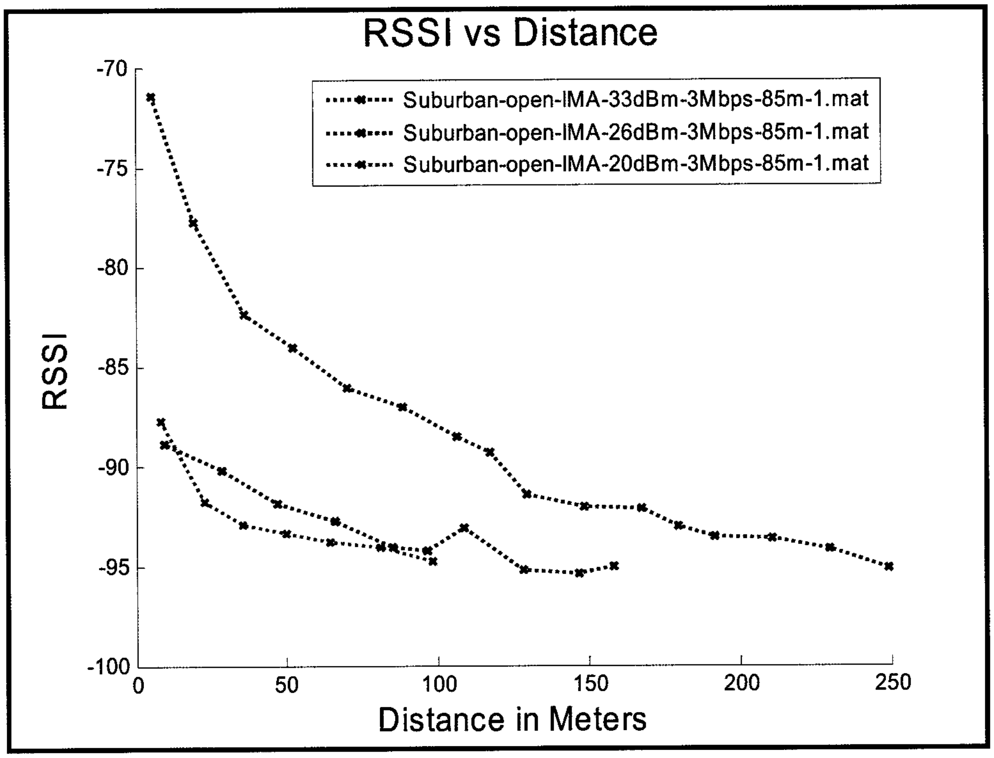


**Figure 51: Comparison of RSSI versus Distance Curves between 20 dBm, 26 dBm, and 33 dBm when the Transmitter was 85 Meters from the Intersection and Set to Transmit at 3 Mbps**

Figure 52 and Figure 53 show the effect of different data rates (3 Mbps and 6 Mbps) at different transmit powers (20 dBm and 33 dBm) for the specific case where the transmitter was 50 meters from the intersection.

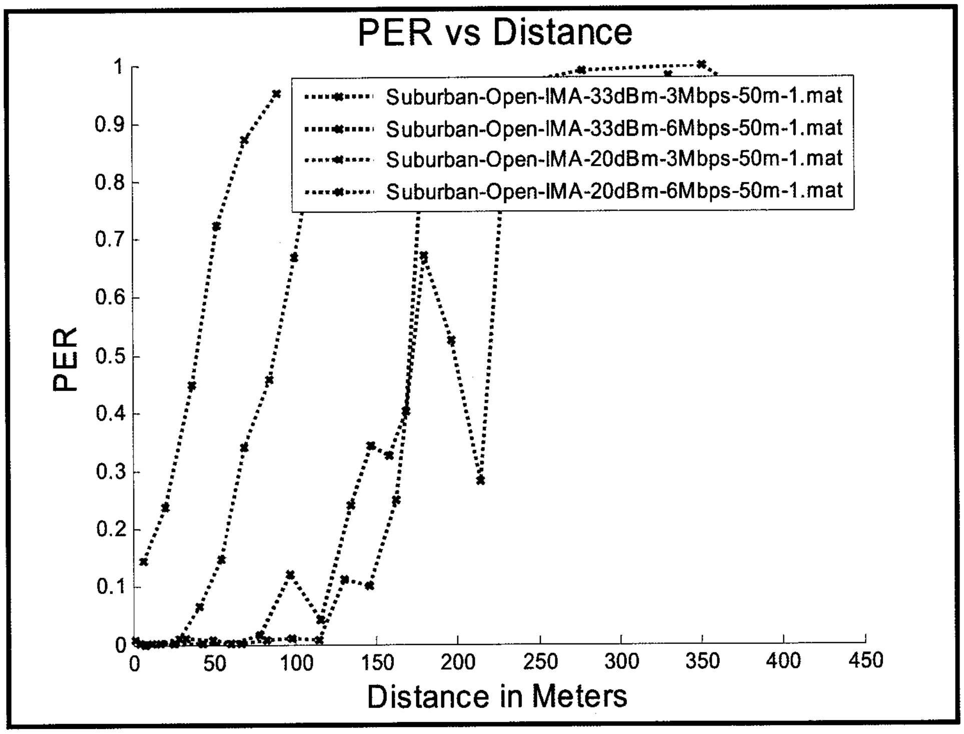


**Figure 52: PER Comparison for Suburban-3/4-Open-Intersection Scenario for 33 dBm and 20 dBm at 3 Mbps and 6 Mbps**

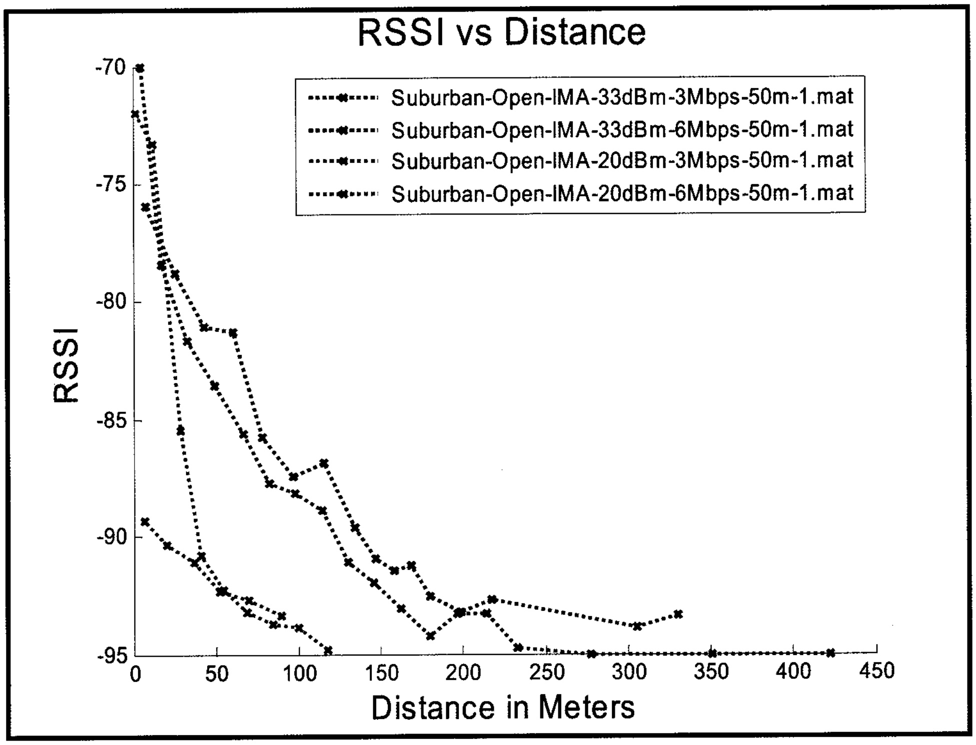


**Figure 53: RSSI Comparison for Suburban-3/4-Open-Intersection Scenario for 33 dBm and 20 dBm at 3 Mbps and 6 Mbps**

## 11.3 Observations for Suburban-¾-Open-Intersection Scenario

The following observations can be drawn with regard to communication performance in a Suburban -¾-Open-Intersection Scenario:

1. Use of lower powers (20 dBm or lower) offers limited communication range around NLOS corners. For example, Figure 50 shows that the signal from a 20 dBm transmitter 85 meters from the intersection could not be decoded reliably until the receiver was within a few meters of the intersection.
2. By contrast, the signal from a 33 dBm transmitter was reliably decoded when the receiver was still more than 100 meters from the intersection
3. For 20 dBm transmissions, the lower 3 Mbps bit rate offers approximately a 50 meter advantage, for a given PER, compared to the 6 Mbps bit rate. For 33 dBm transmissions, the advantage for 3 Mbps is noticeable, but not significant.

## 11.4 Comparison of Suburban-Closed-Intersection and Suburban-Open-Intersection Scenarios

Figure 54 and Figure 55 offer a comparison between the Closed-Intersection and ¾-Open-Intersection Scenario tests in a suburban setting. Only one transmitter location (50 meters) is used for the comparison. It is interesting to note that the Open Intersection case resulted in more reliable communications, extending the range where the receiver experiences 10 percent PER or less from about 80 meters to about 120 meters. This is consistent with a similar comparison in the urban intersection environments (see Section 9.4).

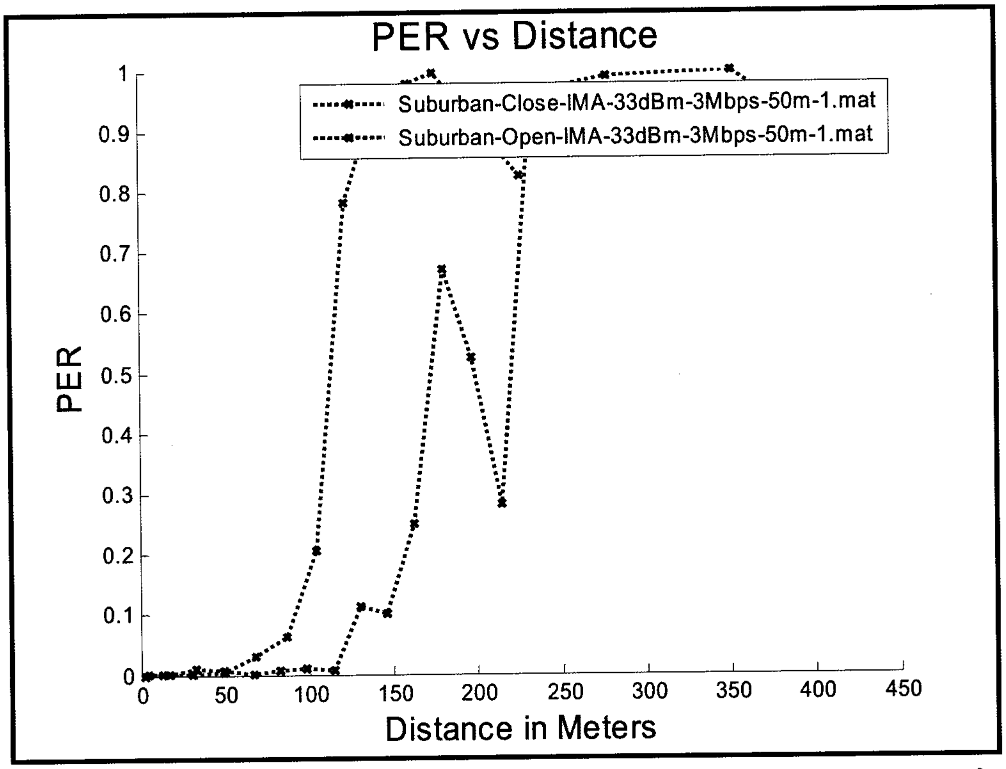


**Figure 54: PER Comparison of Suburban-Closed-Intersection and Suburban-Open-Intersection Scenarios for 33 dBm at 3 Mbps**

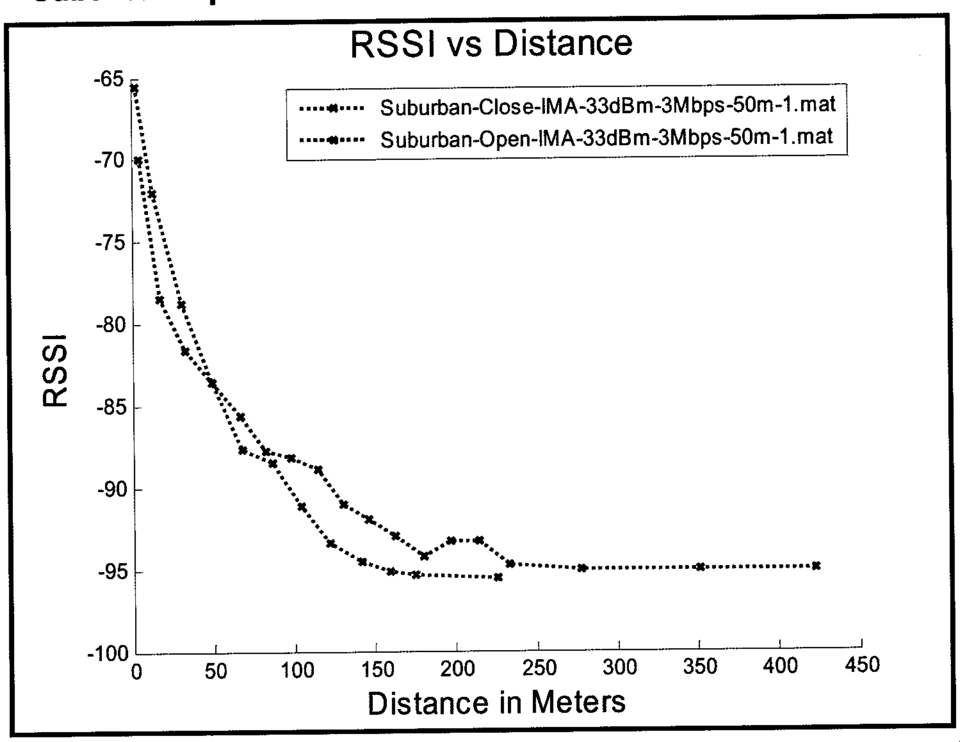


**Figure 55: RSSI Comparison of Suburban-Closed-Intersection and Suburban-Open-Intersection Scenarios for 33 dBm at 3 Mbps**

# 12 Rural-Closed-Intersection Scenario Test

The Rural-Closed-Intersection Scenario test was conducted in Morgan Hill, California, on the corner of Miramonte Avenue and Dougherty Avenue. The test is categorized as a Closed Intersection test because of the presence of homes or trees on all four corners of the intersection. The transmitter was placed at 4 fixed points along Dougherty Avenue southeast of the intersection (distances 0 meters, 25 meters, 50 meters, and 100 meters), while the receiver drove northeast toward the intersection on Miramonte Avenue at a speed of 5 mph. The test cases outlined in Table 8 were repeated for each of the transmitter positions.

**Table 8: Test Cases for the Rural-Closed-Intersection Scenario**

| TX Power / Data Rate | 5dBm | 10dBm | 20dBm | 26dBm | 33dBm |
|---|---|---|---|---|---|
| 3Mbps | Test 1 | Test 3 | Test 5 | Test 7 | Test 9 |
| 6Mbps | Test 2 | Test 4 | Test 6 | Test 8 | Test 10 |

## 12.1 Location Overview

The south corner of the intersection, which separated the transmitter and receiver vehicles, included a home, trees, and fence, all of which interrupted LOS communication. The other three corners were occupied by trees and/or buildings, although these were not as close to the corner as in the Closed-Urban-Intersection and Suburban-Intersection Scenarios. By definition, a closed intersection involving man-made obstructions is somewhat unusual in a rural setting.

## 12.2 Data Analysis

Figure 56 and Figure 57 show PER and RSSI versus distance curves for a 33 dBm transmission at various transmitter locations. It can be seen that as the transmitter moves away from the intersection, communication performance worsens.

Figure 58 and Figure 59 show the relationship between communication performance at 3 different power levels (20 dBm, 26 dBm, and 33 dBm).

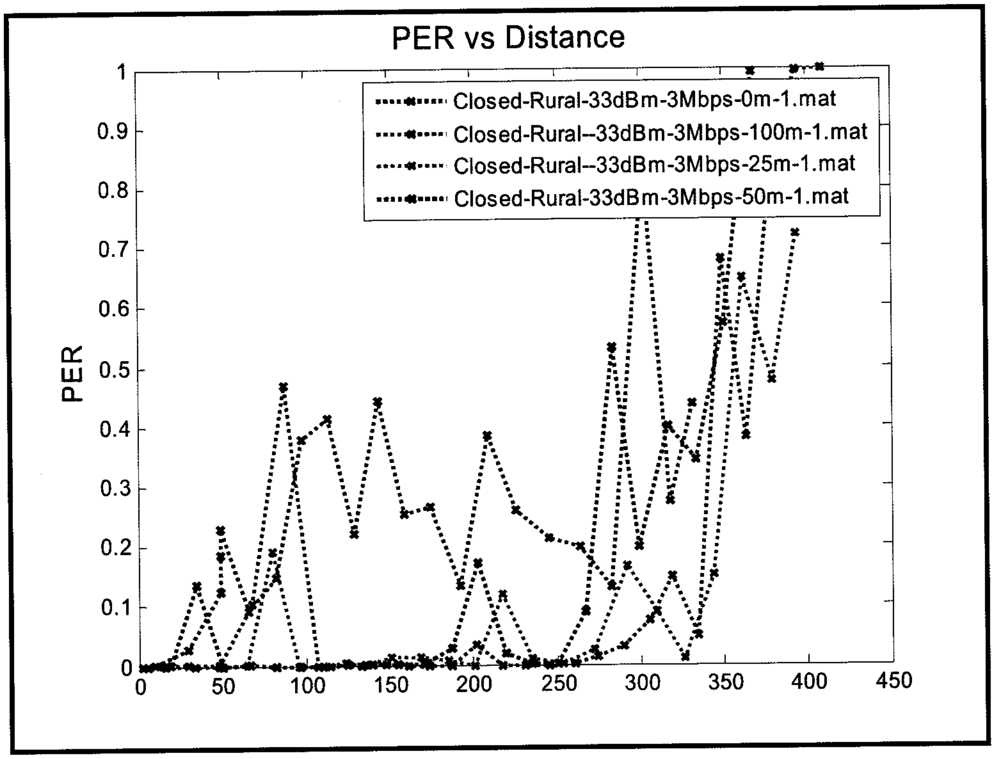


**Figure 56: PER versus Distance Curves for Various Transmitter Locations at 33 dBm and 3 Mbps**

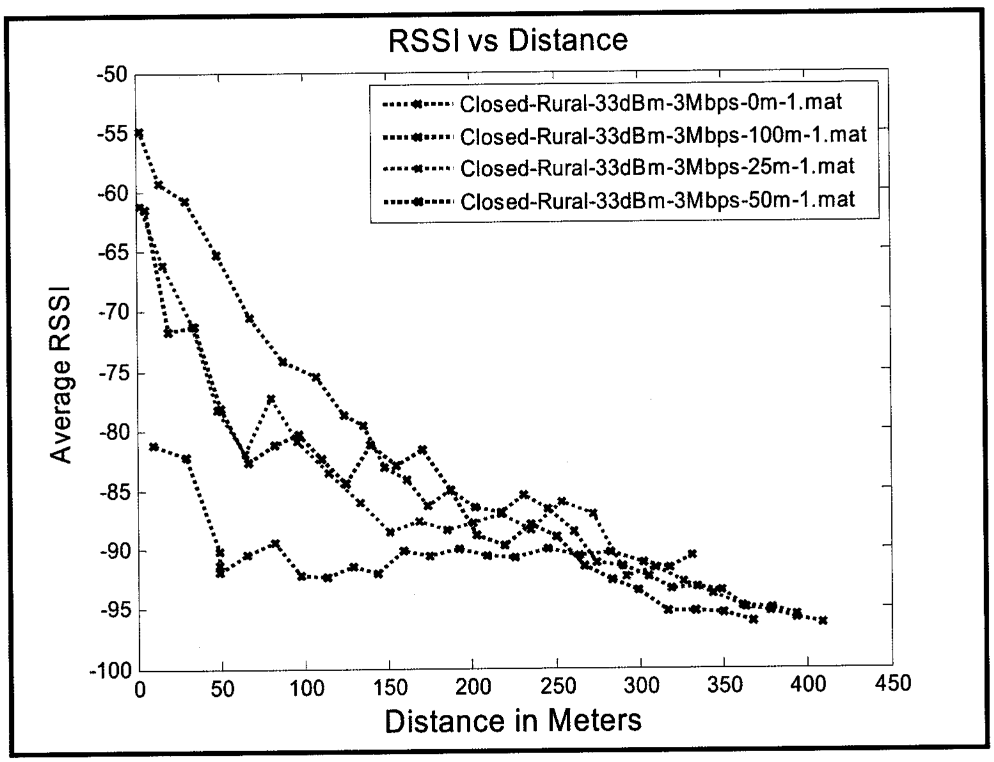


**Figure 57: RSSI versus Distance Curves for Various Transmitter Locations at 33 dBm and 3 Mbps**

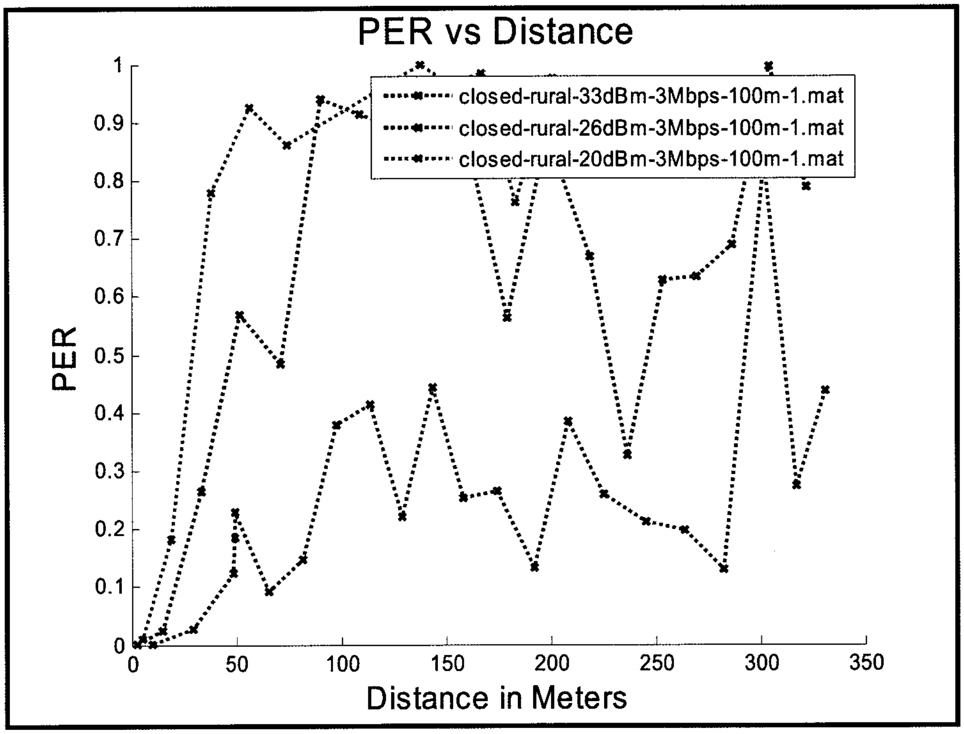


**Figure 58: Comparison of PER versus Distance Curves between 20 dBm, 26 dBm, and 33 dBm when the Transmitter was 100 Meters from the Intersection and Set to Transmit at 3 Mbps**

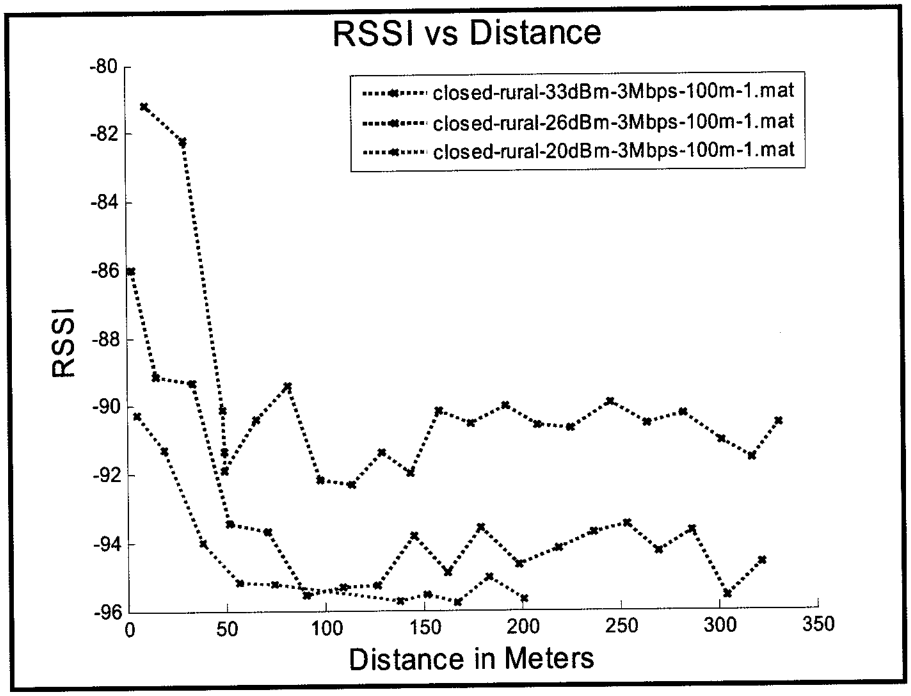


**Figure 59: Comparison of RSSI versus Distance Curves between 20 dBm, 26 dBm, and 33 dBm when the Transmitter was 100 Meters from the Intersection and Set to Transmit at 3 Mbps**

## 12.3 Observations for Rural-Closed-Intersection Scenario

The following observations can be drawn with regard to communication performance in a Rural-Closed-Intersection Scenario:

1. Use of lower powers (20 dBm or lower) offers limited communication range around NLOS corners at the rural intersection. Figure 58 shows that for a 20 dBm transmission the PER rises to approximately 80 percent at the 50 meter mark.
2. In the 33 dBm transmission, however, the PER is about 25 percent at 50 meters and remains below 50 percent beyond 250 meters.
3. There seems to be less sensitivity to transmitter-to-intersection distance in this scenario than in the Urban and Suburban closed intersection scenarios. For example, in Figure 56 the performance for transmitter distances of 0 meters, 25 meters, and 50 meters is similar; they all have low PER (ignoring narrow spikes) out to at least 250 meters receiver distance, and they all transition to high PER over about a 150 meter range starting at 250 meters. This contrasts with Figure 22 and Figure 42, in which the transition from low to high PER occurs in non-overlapping distance ranges for the 0 meters, 25 meters (urban only), and 50 meters transmitter-to-intersection cases.

# 13 Rural-¾-Open-Intersection Scenario Test

The Rural-¾-Open-Intersection Scenario tests were conducted in Morgan Hill, California, on the corner of Miramonte Avenue and Hale Avenue. The test is categorized as a Rural-¾-Open-Intersection Scenario test because of relatively open spaces on 3 out of the 4 corners. The transmitter-to-intersection distance was set at only one location (100 meters), while the receiver drove toward the intersection at the speed of traffic. The test cases outlined in Table 9 were repeated for each of the transmitter positions.

**Table 9: Test Cases for the Rural-¾-Open–Intersection Scenario**

| Data Rate \ TX Power | 20dBm | 26dBm | 33dBm |
|---|---|---|---|
| 3Mbps | Test 1 | Test 3 | Test 5 |
| 6Mbps | Test 2 | Test 4 | Test 6 |

## 13.1 Location Overview

This intersection features a large industrial complex on the west corner, which served as the primary obstruction between the transmitter and receiver. Moving southwest from Hale Avenue, there are about 20 meters of open space before approaching a parking lot lined with trees and a fence and about 30 more meters before approaching a one-story building. Since the building is set back from Hale Avenue by about 50 meters, the transmitter was placed in just one location for this scenario, 100 meters southwest of the intersection on Miramonte. The receiver approached the intersection on Hale, traveling southeast, with the obstruction and transmitter to its right. The other three corners are open. The north corner has a low building set back about 70 meters northeast of Hale and 20 meters northwest of Miramonte. The east and south corners are farm fields.

## 13.2 Data Analysis

Figure 60 and Figure 61 show the RSSI and PER versus distance curves for the Rural-¾-Open Intersection tests.

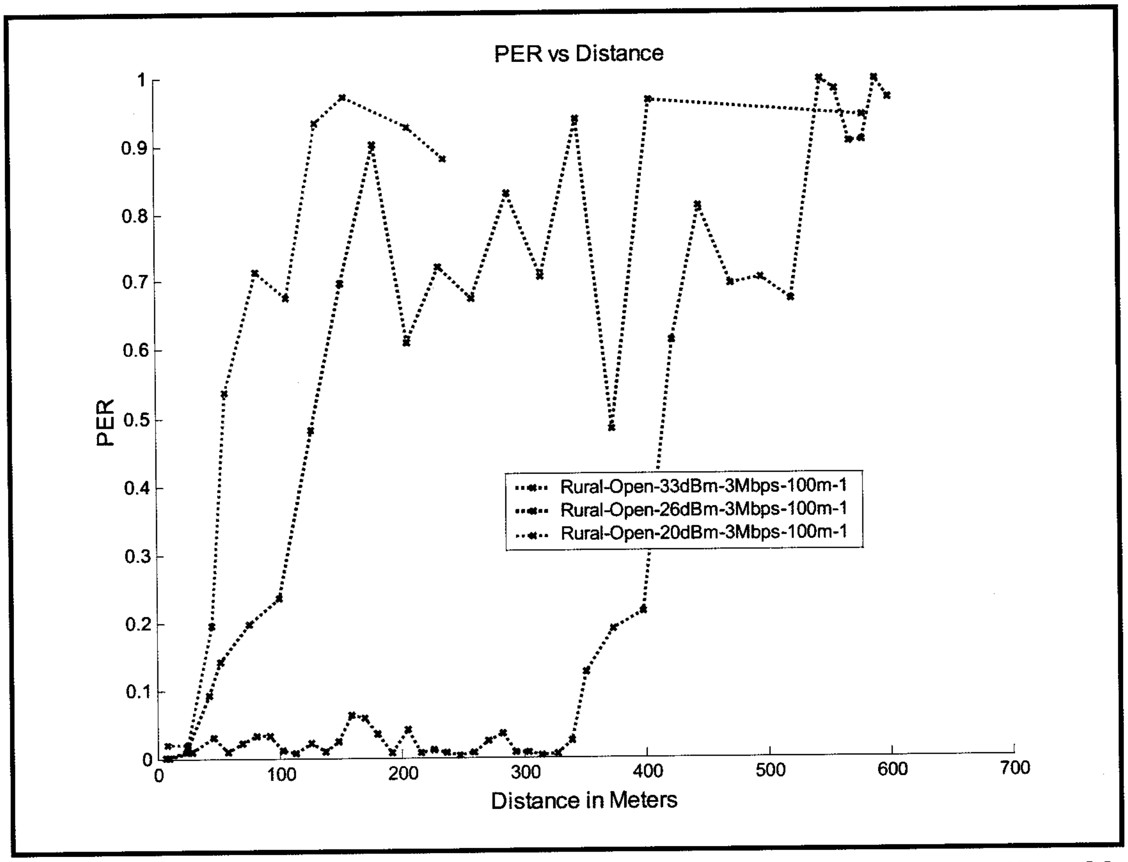


**Figure 60: Comparison of PER versus Distance Curves between 33 dBm, 26 dBm, and 20 dBm when the Transmitter was 100 Meters from the Intersection and Set to Transmit at 3 Mbps**

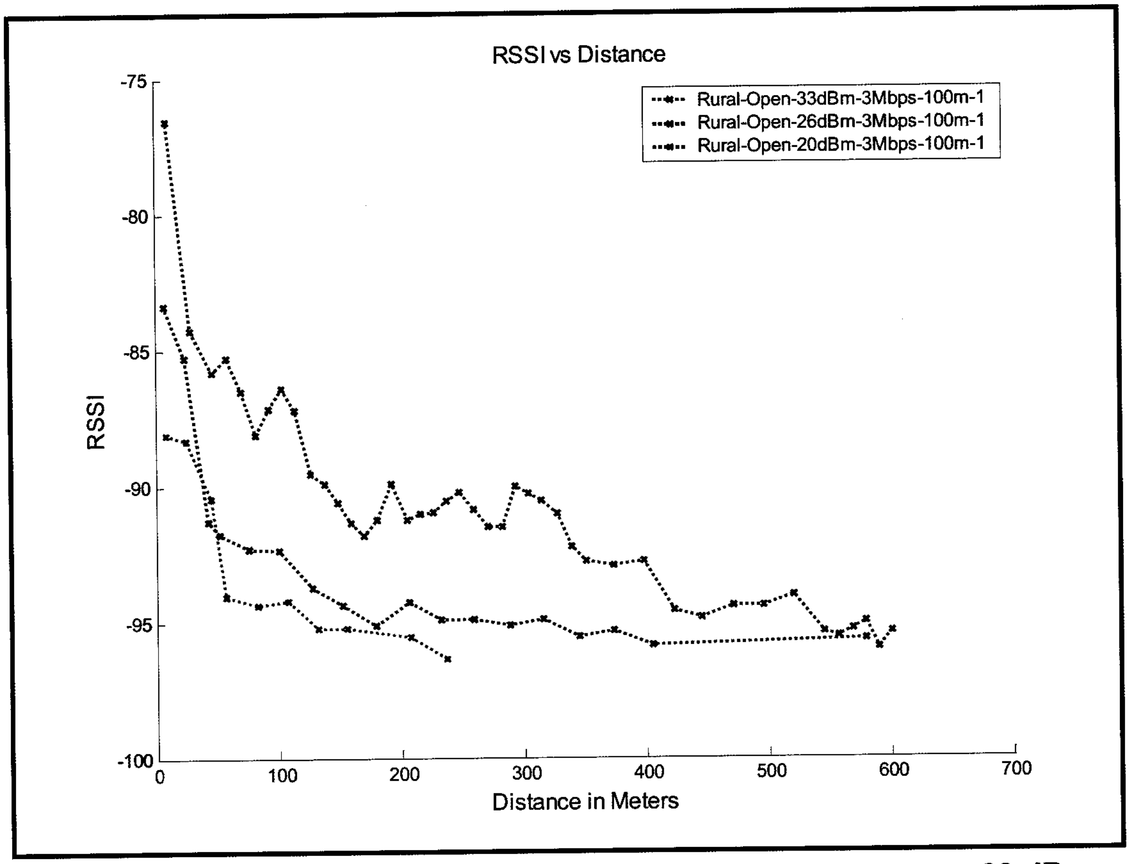


**Figure 61: Comparison of RSSI versus Distance Curves between 33 dBm, 26 dBm, and 20 dBm when the Transmitter was 100 Meters from the Intersection and Set to Transmit at 3 Mbps**

Figure 62 and Figure 63 show the effect of different data rates (3 Mbps and 6 Mbps) at different transmit powers (20 dBm and 33 dBm). It is clear that the lower rate offers a marginal improvement in performance at 33 dBm, while at 20 dBm there is no clear preference between 3 Mbps and 6 Mbps.

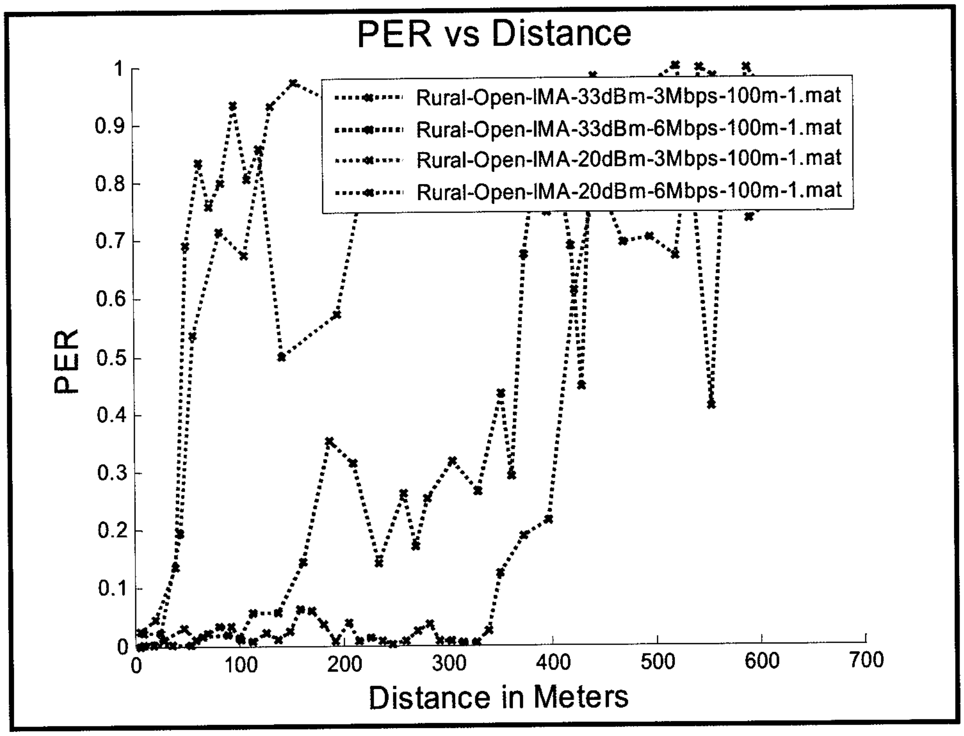


**Figure 62: Comparison of PER Curves in Rural-3/4-Open-Intersection for 33 dBm and 20 dBm at 3 Mbps and 6 Mbps**

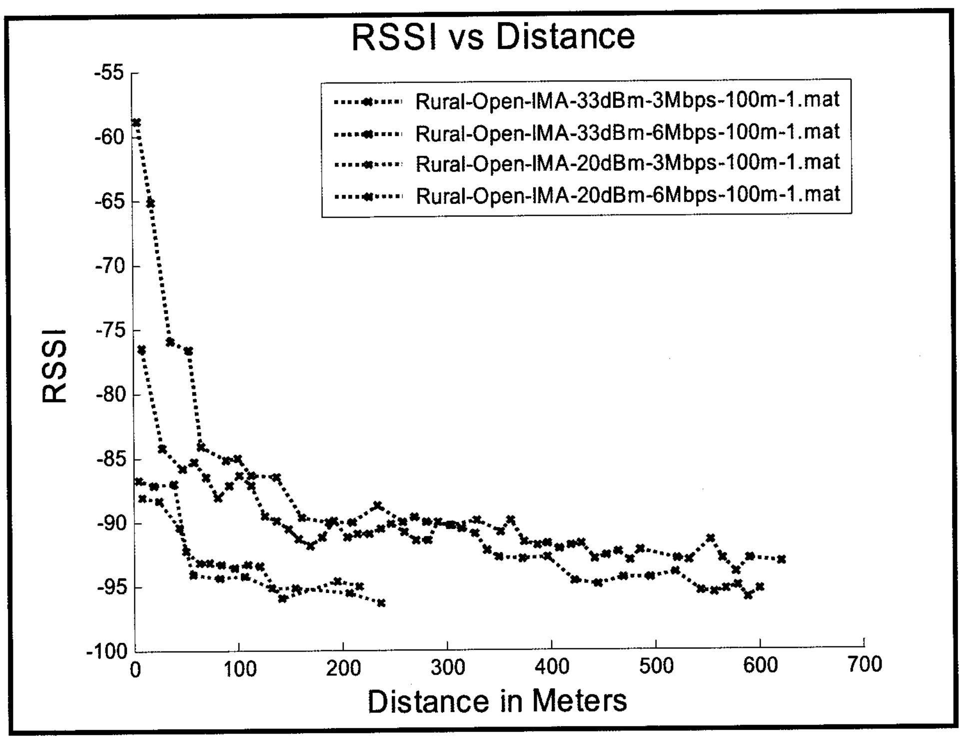


**Figure 63: Comparison of RSSI Curves in Rural-3/4-Open-Intersection for 33 dBm and 20 dBm at 3 Mbps and 6 Mbps**

## 13.3 Observations for Rural-¾-Open–Intersection Scenario

The following observations can be drawn with regard to communication performance in a Rural-¾-Open-Intersection Scenario:

1. Use of lower powers (20 dBm or lower) offers limited communication range around a NLOS corner in this Rural-¾-Open Intersection
2. Both 20 dBm and 26 dBm transmissions offer less than 50 meters of reliable communication range (< 10 percent PER)
3. A 33 dBm transmission offers about 300 meters of reliable communication range.
4. Transmission at a lower data rate (3 Mbps) offers a marginal improvement in communication performance

# 14 Curved-Road Scenario Test

The curved track test was conducted in Cupertino, California, along Stevens Canyon Road at a point where the road goes through an approximate 90 degree turn. The transmitter was placed at one of two fixed locations, 50 meters and 100 meters west of the curve. The receiver drove toward the transmitter southward and then curved to the west. The test was repeated for the test cases shown in Table 10.

**Table 10: Test Cases for the Curved-Road Scenario**

| TX Power / Data Rate | 5dBm | 10dBm | 15dBm | 20dBm | 26dBm | 33dBm |
|---|---|---|---|---|---|---|
| 3Mbps | Test 1 | Test 4 | Test 7 | Test 10 | Test 13 | Test 16 |
| 6Mbps | Test 2 | Test 5 | Test 8 | Test 11 | Test 14 | Test 17 |
| 12Mpbs | Test 3 | Test 6 | Test 9 | Test 12 | Test 15 | Test 18 |

## 14.1 Location Overview

Figure 64 and Figure 65 illustrate the propagation environment in the Curved-Road Scenario test. The curve veers toward the right (west) as vehicles drive south on Stevens Canyon Road. The primary obstruction was the presence of a hill on the bend.

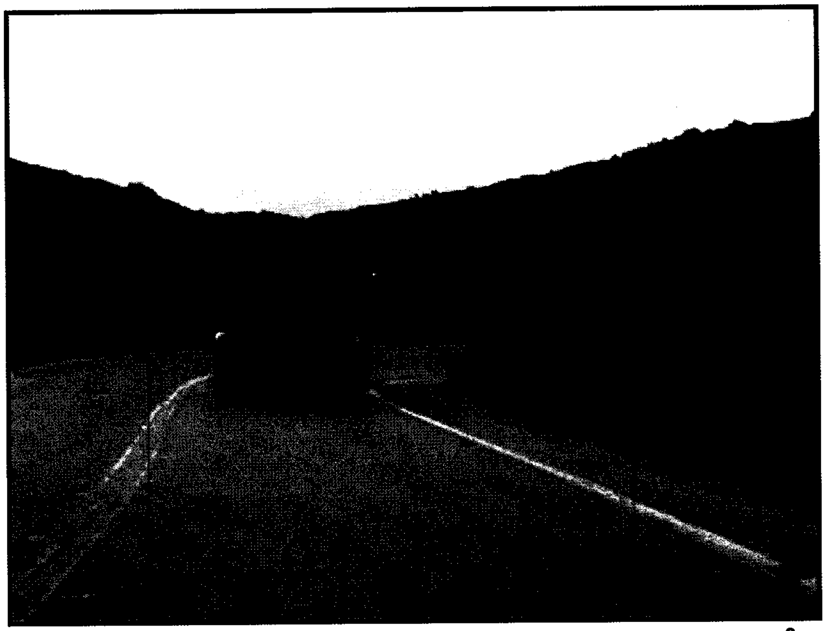

**Figure 64: Heading South on Stevens Canyon Road[3]**

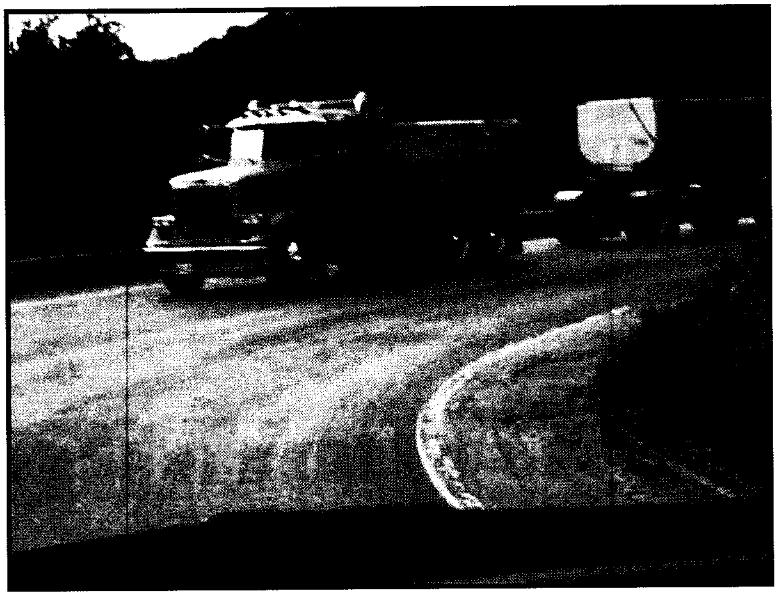

**Figure 65: Negotiating the Curve**

[3] Note that the photos in Figure 64 and Figure 65 were taken after the testing was completed, and the trucks shown were not present during the tests.

## 14.2 Data Analysis

Figure 66 and Figure 67 offer a comparison of PER and RSSI curves in a curved track scenario for a transmission at 33 dBm and 3 Mbps. The curves illustrate the PER/RSSI values when the transmitter is 50 meters and 100 meters from the bend of the curve.

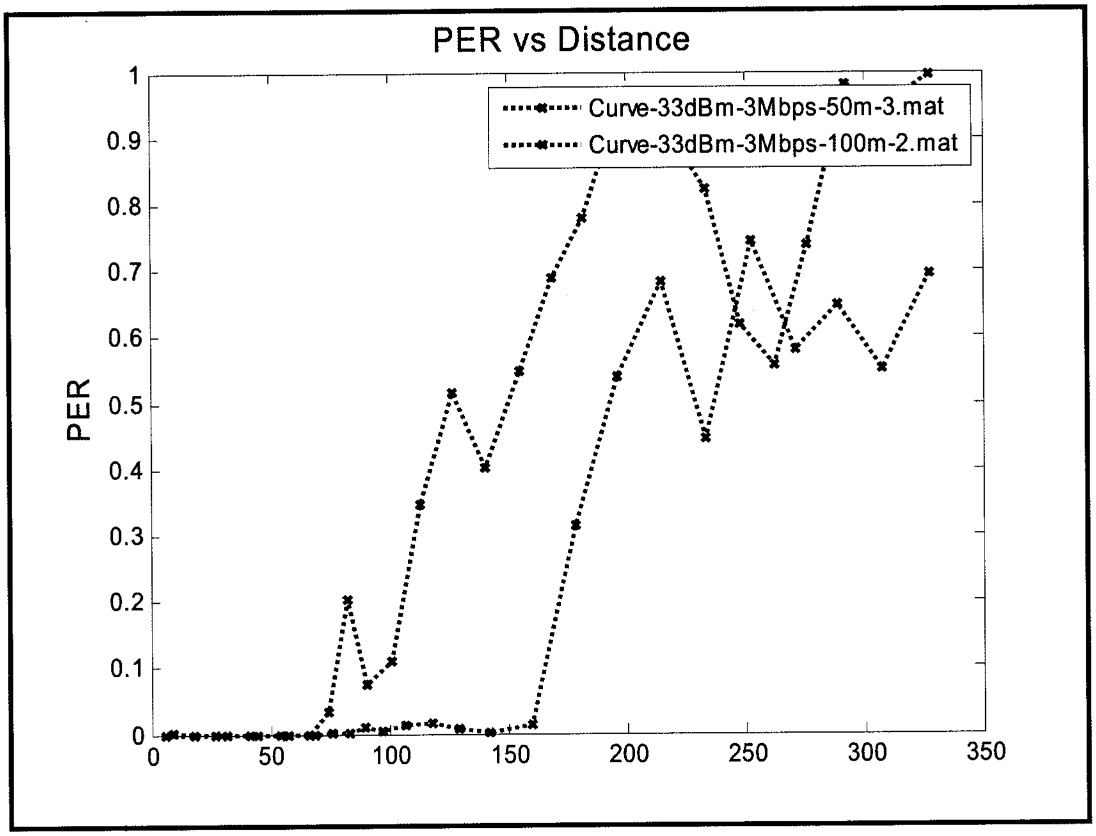


**Figure 66: Comparison of PER Curves for Curved-Road Scenario at 50 Meters and 100 Meters for 33 dBm Transmission**

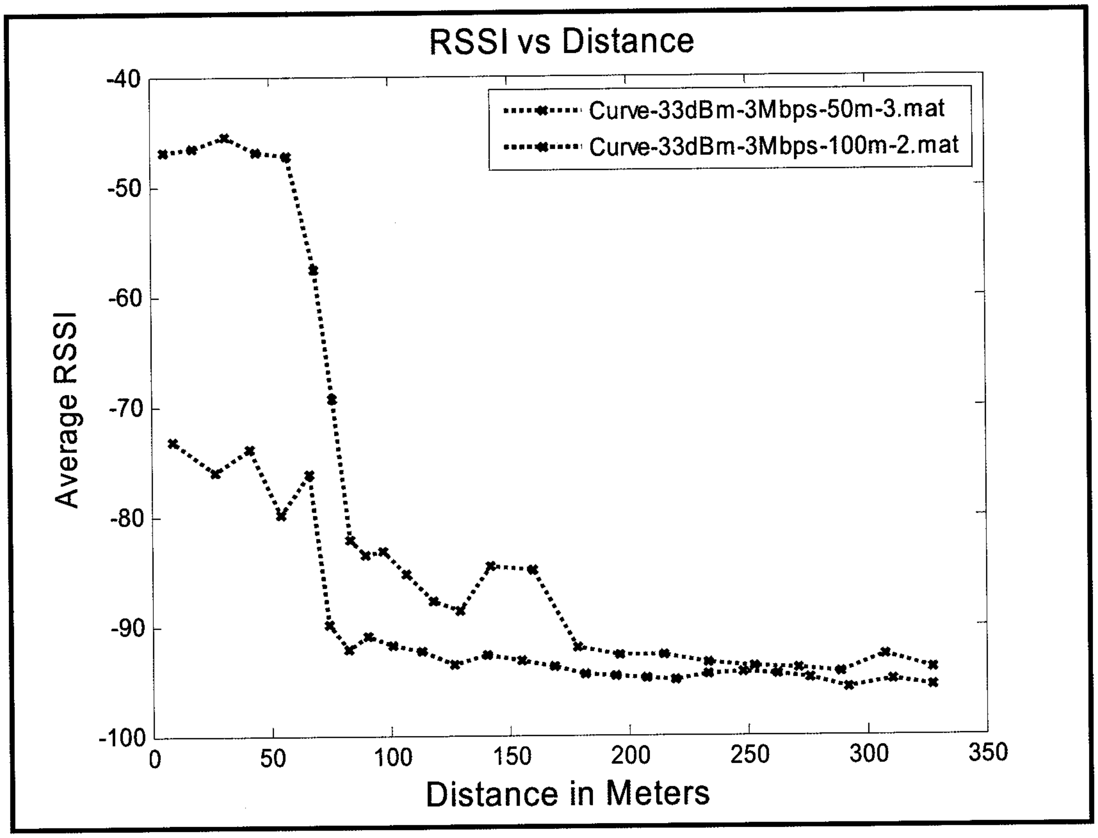


**Figure 67: Comparison of RSSI Curves for Curved-Road Scenario at 50 Meters and 100 Meters for 33 dBm Transmission**

Figure 68 and Figure 69 show PER and RSSI curves for 3 different power levels (20 dBm, 26 dBm, and 33 dBm) with a transmitter-to-curve distance of 50 meters.

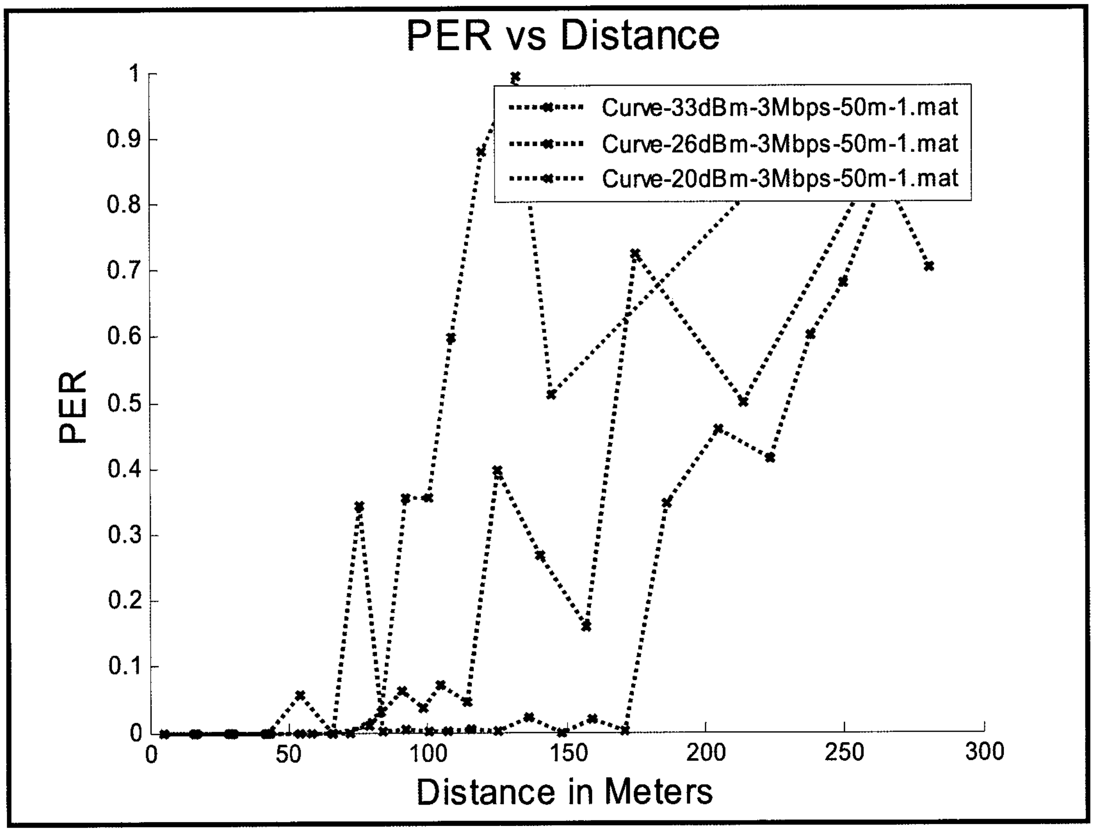


**Figure 68: Comparison for PER Curves for a Curved-Road Scenario for 33 dBm, 26 dBm, and 20 dBm Transmissions**

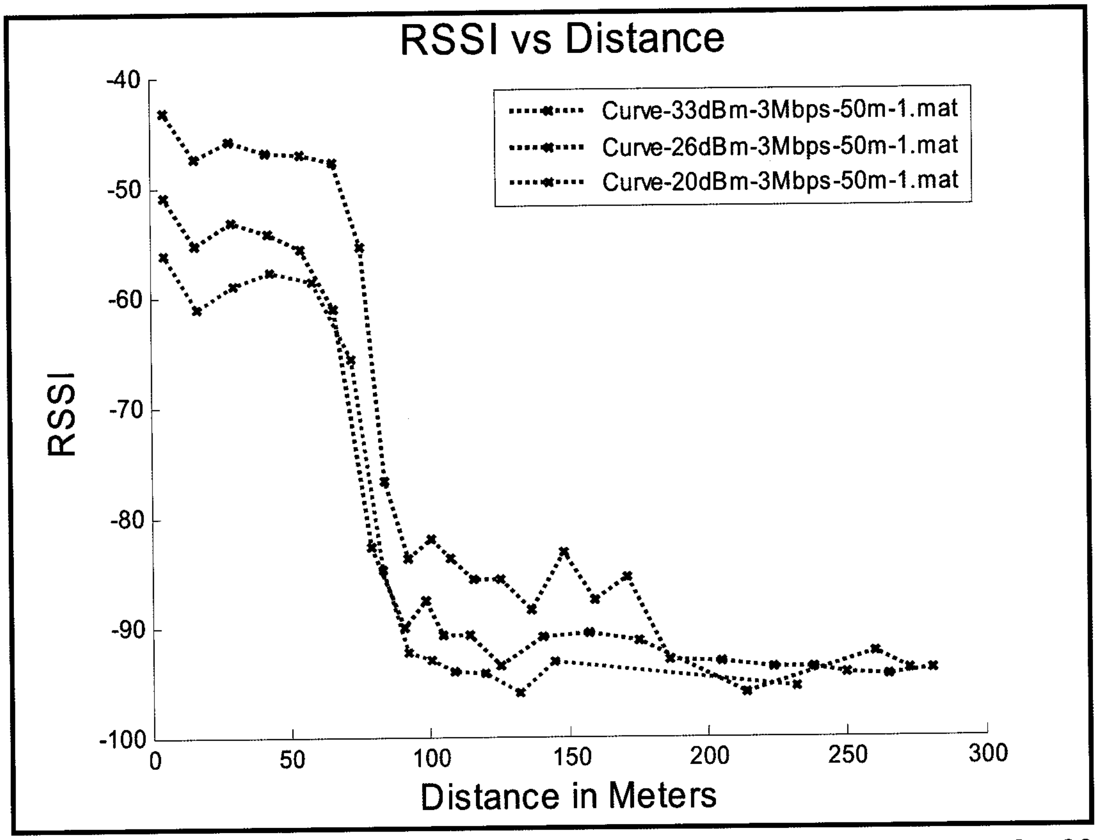


**Figure 69: Comparison for RSSI Curves for a Curved-Road Scenario for 33 dBm, 26 dBm, and 20 dBm Transmissions**

Figure 70 and Figure 71 show the effect of different data rates (3 Mbps and 6 Mbps) at different transmit powers (20 dBm and 33 dBm). The 3 Mbps rate offers somewhat better performance at 33 dBm. The comparison at 20 dBm shows a slight advantage for 3 Mbps.

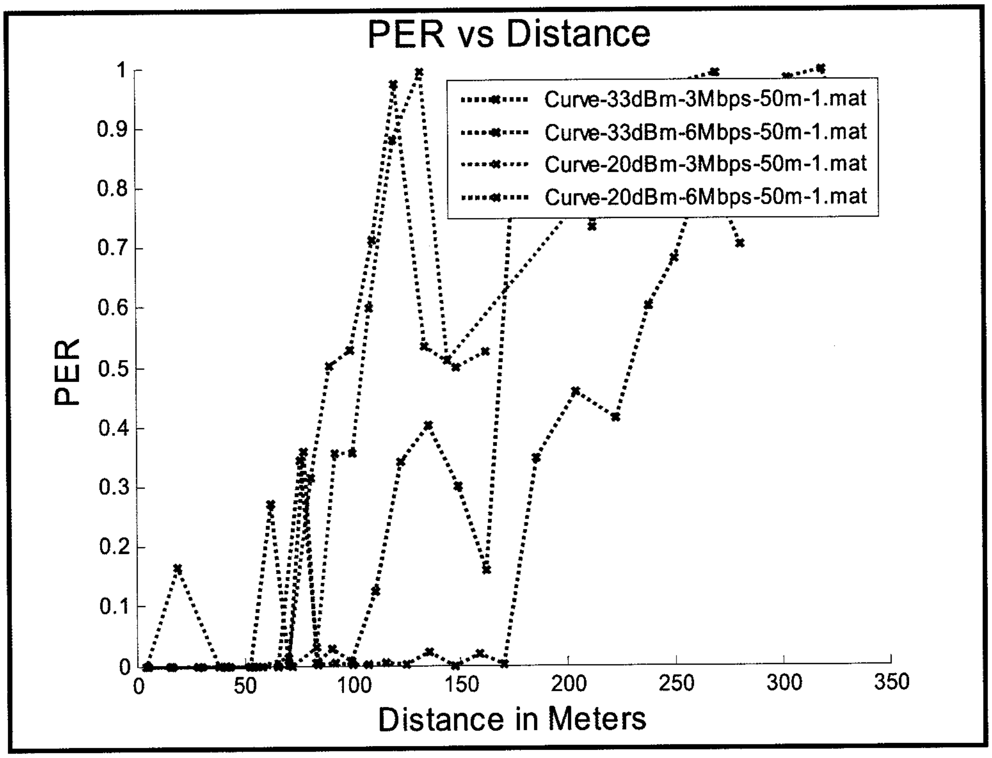


**Figure 70: Comparison of PER Curves in a Curved-Road Scenario for 33 dBm and 20 dBm at 3 Mbps and 6 Mbps**

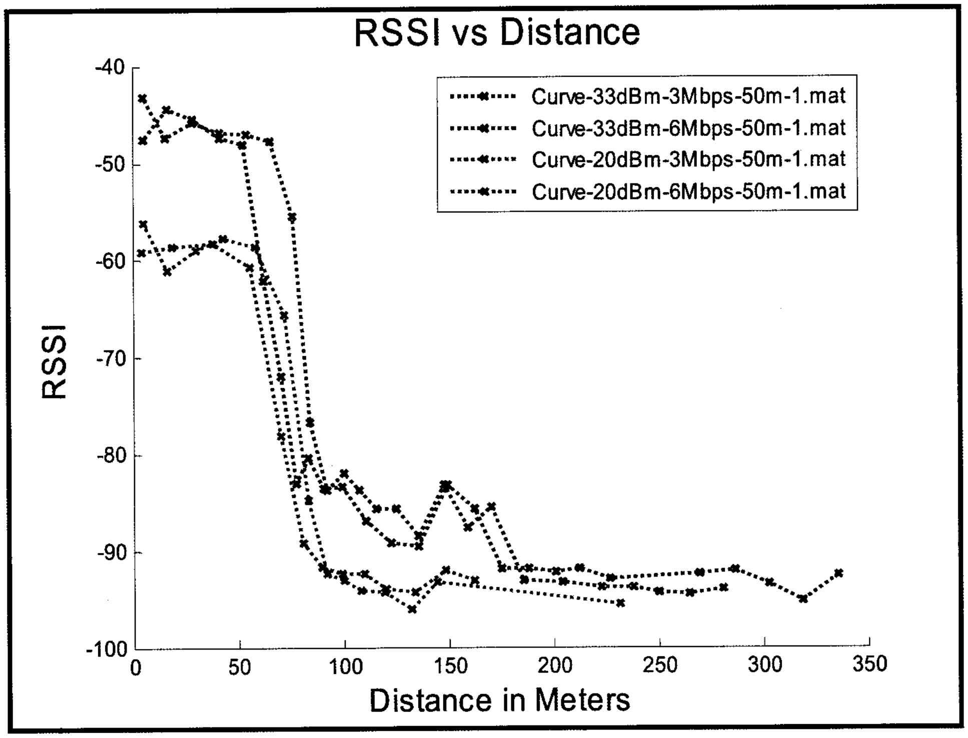


**Figure 71: Comparison of RSSI Curves in a Curved-Road Scenario Test for 33 dBm and 20 dBm at 3 Mbps and 6 Mbps**

## 14.3 Observations for Curved-Road Scenario Test

The following observations can be drawn with regard to communication performance in a Curved-Road Scenario:

1. When the transmitter is 100 meters from the bend, a reliable communication link is achieved only when the receiver is 70 meters from the bend or less (Figure 66)
2. Use of lower powers (20 dBm or lower) offers limited communication range around NLOS corners. We can see in Figure 68 that the 20 dBm transmission offers less than 100 meters for reliable communication range, whereas the 26 dBm and 33 dBm transmissions maintain a reliable link well beyond the 100 meter range.
3. The advisability of employing higher powers in a Curved Road test depends on the range requirements of applications that will be active in such a scenario. .

# 15 Freeway-Line-of-Sight Scenario Test

In this test V2V communication performance was measured along an open freeway without any intentional obstructions or occlusions. The receiver drove at a constant speed of 55 mph while the transmitter varied its speed to obtain a wide range of V2V distances. The test was repeated for all the cases outlined in Table 11.

**Table 11: Test Cases for the Freeway-LOS Scenario**

| Data Rate \ TX Power | 5dBm | 10dBm | 20dBm | 33dBm |
|---|---|---|---|---|
| 3Mbps | Test 1 | Test 3 | Test 5 | Test 7 |
| 6Mbps | Test 2 | Test 4 | Test 6 | Test 8 |

## 15.1 Location Overview

The V2V Freeway tests were conducted along US-101 in California. US-101 is a 3-4 lane highway with moderate, free-flowing traffic (see Figure 72). There was a 3-foot high median separating traffic in either direction (concrete in some places and steel in others). The freeway was curved and hilly in some sections which might have resulted in temporary loss of LOS and higher PER even though the V2V distance was nominally within communication range.

**Figure 72: Heading South on US-101**

## 15.2 Data Analysis

Figure 73 and Figure 74 show the PER and RSSI versus distance curves for the freeway LOS tests. The results were fairly consistent with higher powers offering a longer communication range. The spike above 10 percent PER for the 33 dBm case at about

300 meters corresponded to a curve in the road, which interrupted LOS communication temporarily.

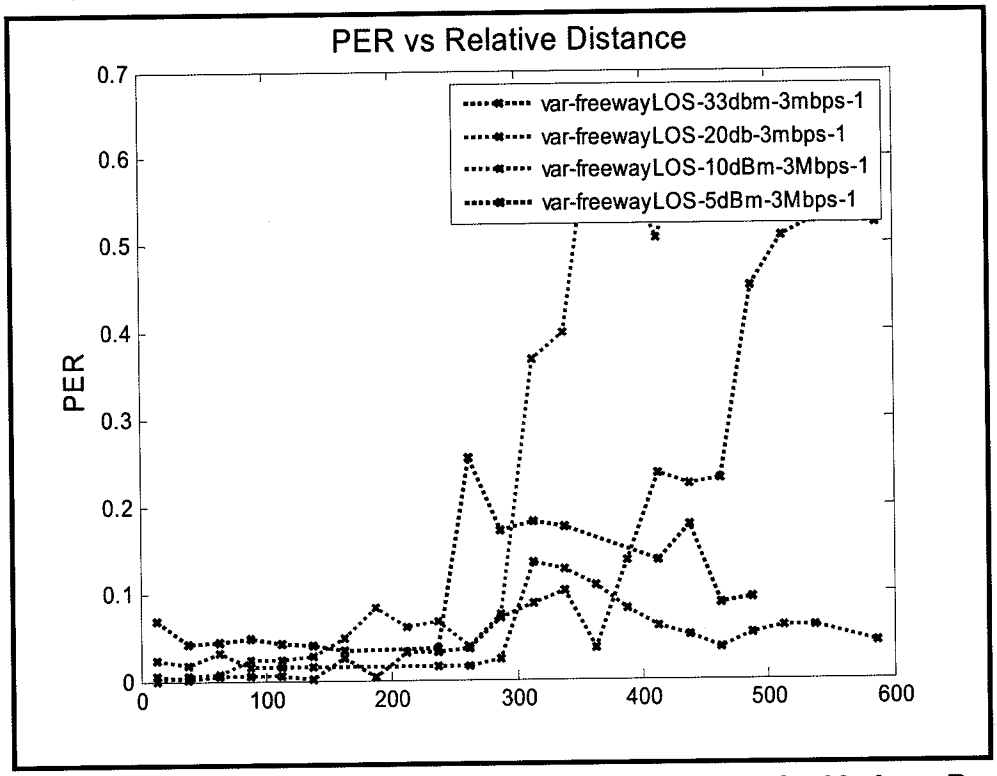


**Figure 73: Comparison of PER versus Distance Curves for Various Power Levels in a Freeway-LOS Scenario when Transmitter is Set to 3 Mbps**

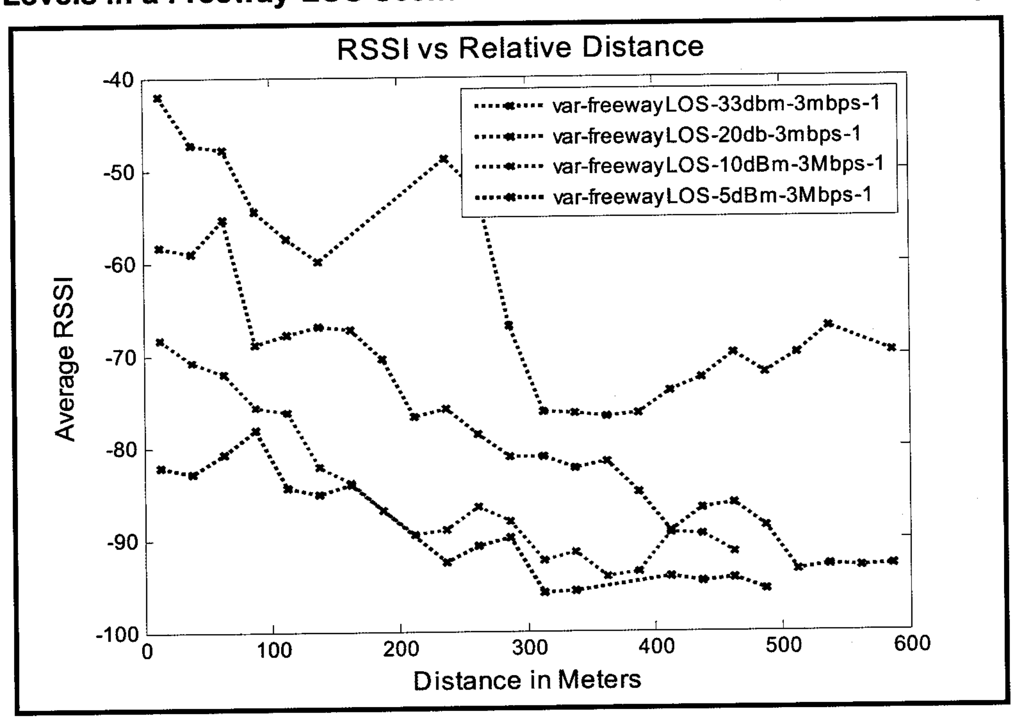

**Figure 74: Comparison of RSSI versus Distance Curves for Various Power Levels in a Freeway-LOS Scenario when Transmitter is Set to 3 Mbps**

Figure 75 and Figure 76 show the effect of different data rates (3 Mbps and 6 Mbps) at different transmit powers (10 dBm and 20 dBm). In contrast to earlier tests, the 6 Mbps rate appears to have better performance than the 3 Mbps rate at 20 dBm. At 10 dBm the performance is similar at each rate, with a small advantage for 3 Mbps.

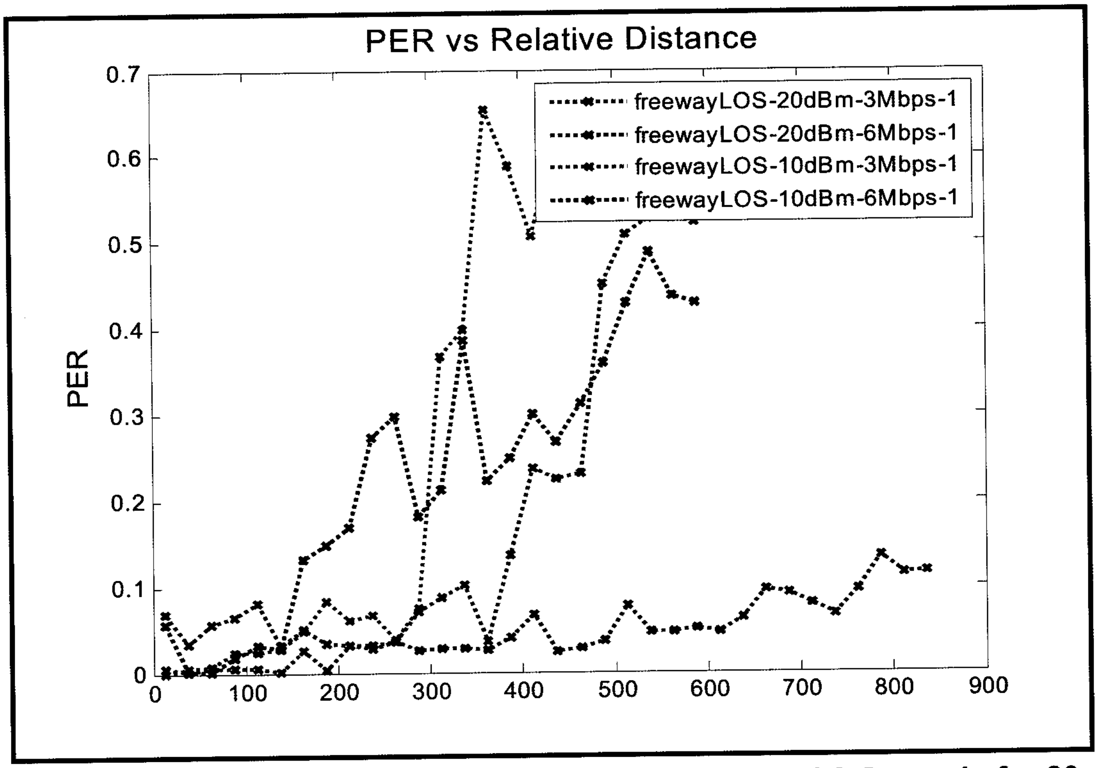


**Figure 75: Comparison of PER Curves in a Freeway-LOS Scenario for 20 dBm and 10 dBm at 3 Mbps and 6 Mbps**

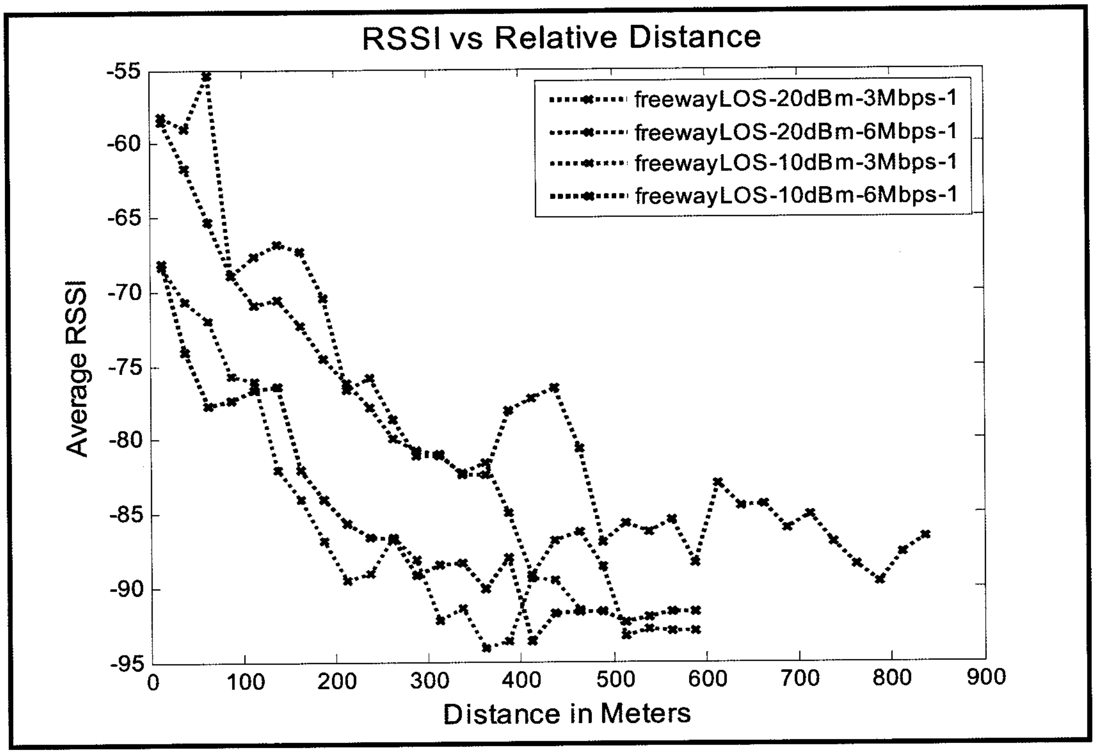


**Figure 76: Comparison of RSSI Curves in a Freeway-LOS Scenario for 33 dBm and 20 dBm at 3 Mbps and 6 Mbps**

## 15.3 Observations for Freeway LOS Scenario Testing

The following observations can be drawn with regard to communication performance in a Freeway LOS Scenario:

1. All the power levels (5 dBm-33 dBm) offer reliable communication (PER < 10 percent) up to at least 225 meters
2. 20 dBm transmissions offer reliable communication up to 375 meters
3. 33 dBm transmissions offer reliable communication for the entire 600 meter range tested

# 16 Rural-Highway, Line-of-Sight Scenario Test

The Rural-Highway LOS Scenario test was conducted in Morgan Hill, California, along Hale Avenue. The receiver maintained a constant speed of 45 mph while the transmitter varied its speed to obtain a wide range of V2V distances. There were no intentional obstacles between the vehicles. The rural highway tests were conducted for the test cases outlined in Table 12.

**Table 12: Test Cases for the Rural-Highway–LOS Scenario**

| TX Power / Data Rate | 10dBm | 20dBm | 33dBm |
|---|---|---|---|
| 3Mbps | Test 1 | Test 3 | Test 5 |
| 6Mbps | Test 2 | Test 4 | Test 6 |

## 16.1 Location Overview

Hale Avenue is fairly representative of a rural highway with open fields and occasional trees, houses, or farms on either side of the road. The highway was curved along some sections which might have resulted in temporary loss of LOS and higher PER even though the V2V distance was nominally within communication range.

## 16.2 Data Analysis

Figure 77 and Figure 78 show the PER and RSSI curves for the rural highway LOS tests.

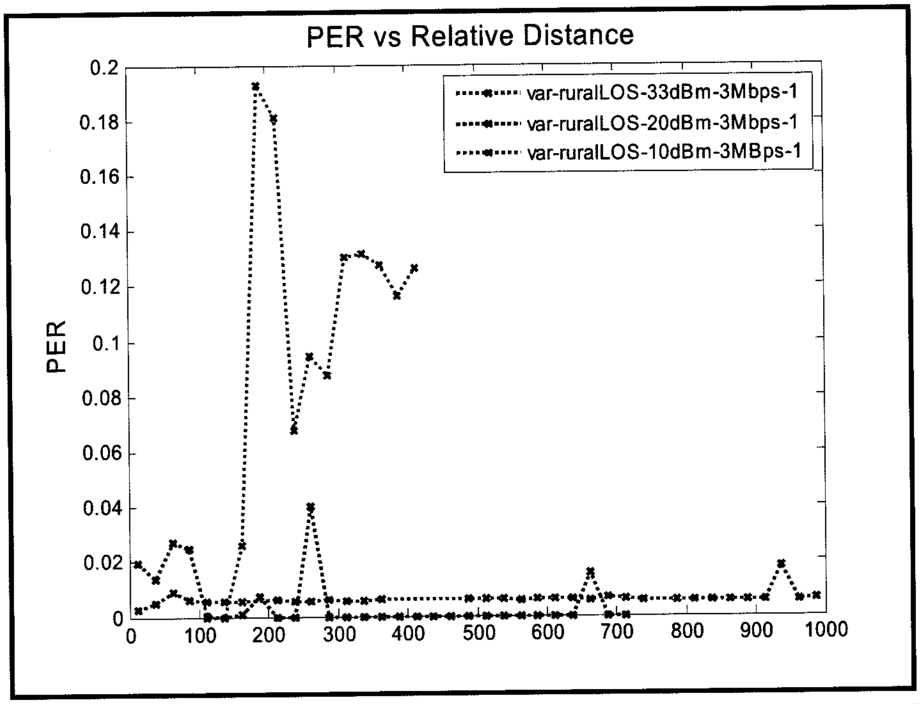


**Figure 77: Comparison of PER versus Distance Curves for Various Power Levels in a Rural-Highway-LOS Scenario when Transmitter is Set to 3 Mbps**

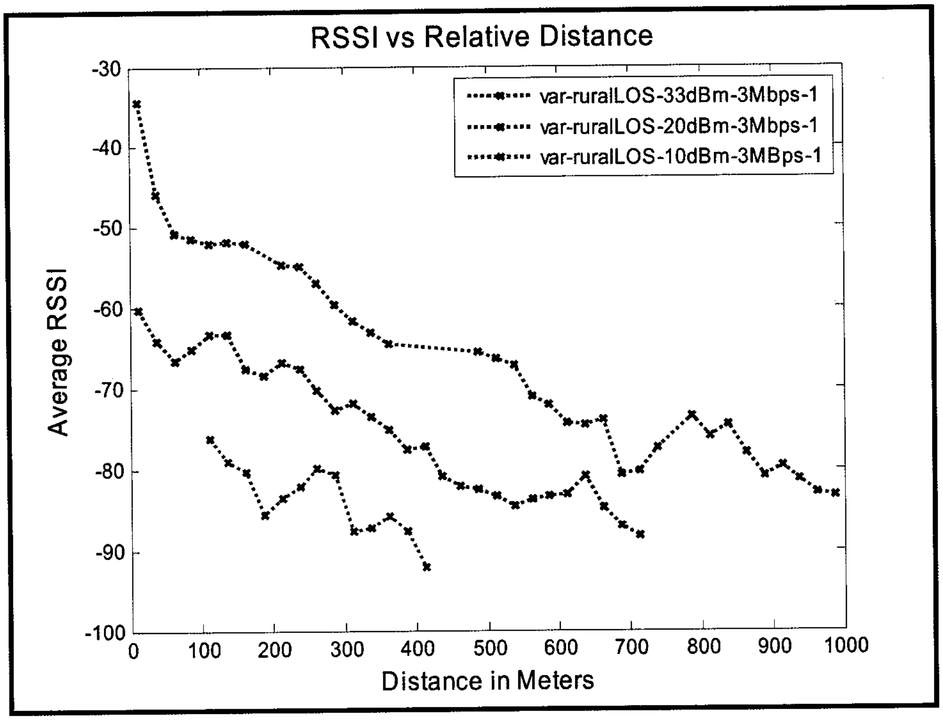


**Figure 78: Comparison of RSSI versus Distance Curves for Various Power Levels in a Rural-Highway-LOS Scenario when Transmitter is Set to 3 Mbps**

Figure 79 and Figure 80 show the effect of different data rates (3 Mbps and 6 Mbps) at different transmit powers (20 dBm and 33 dBm). The 6 Mbps/33 dBm run was only able to collect data for distances up to about 350 meters. There is a marginal PER advantage for 3 Mbps at 33 dBm over the range tested and a more noticeable range advantage for 3 Mbps at 20 dBm.

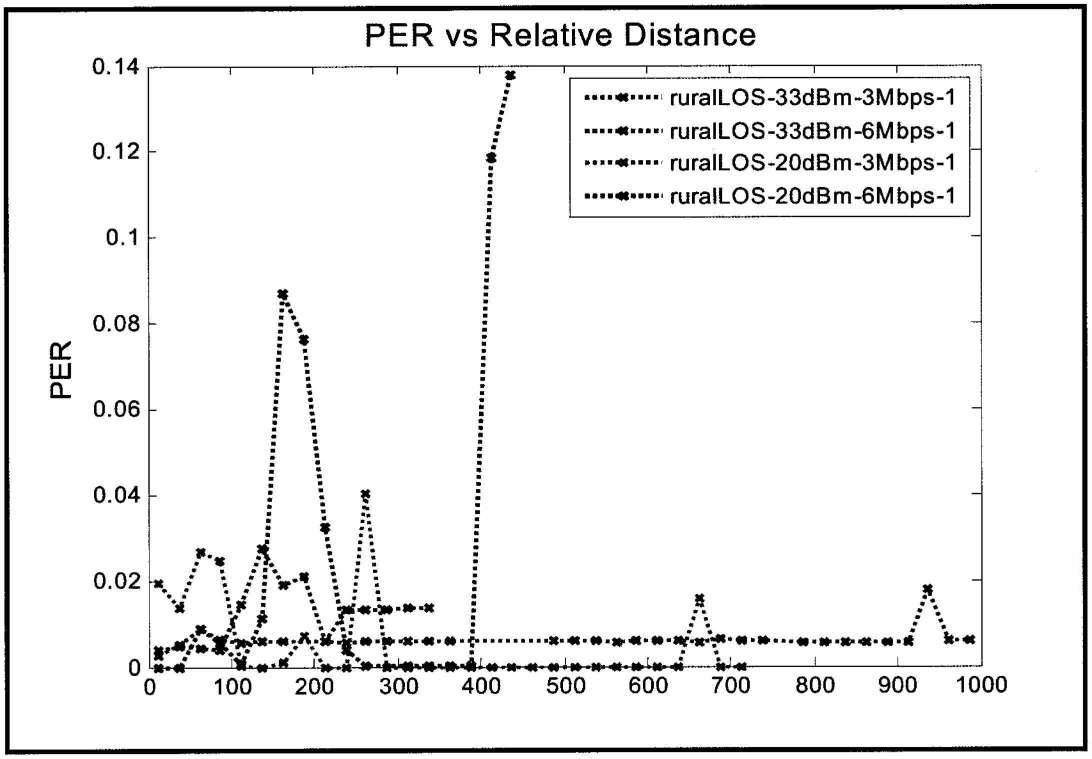


**Figure 79: Comparison of PER Curves in a Rural-Highway-LOS Scenario for 33 dBm and 20 dBm at 3 Mbps and 6 Mbps**

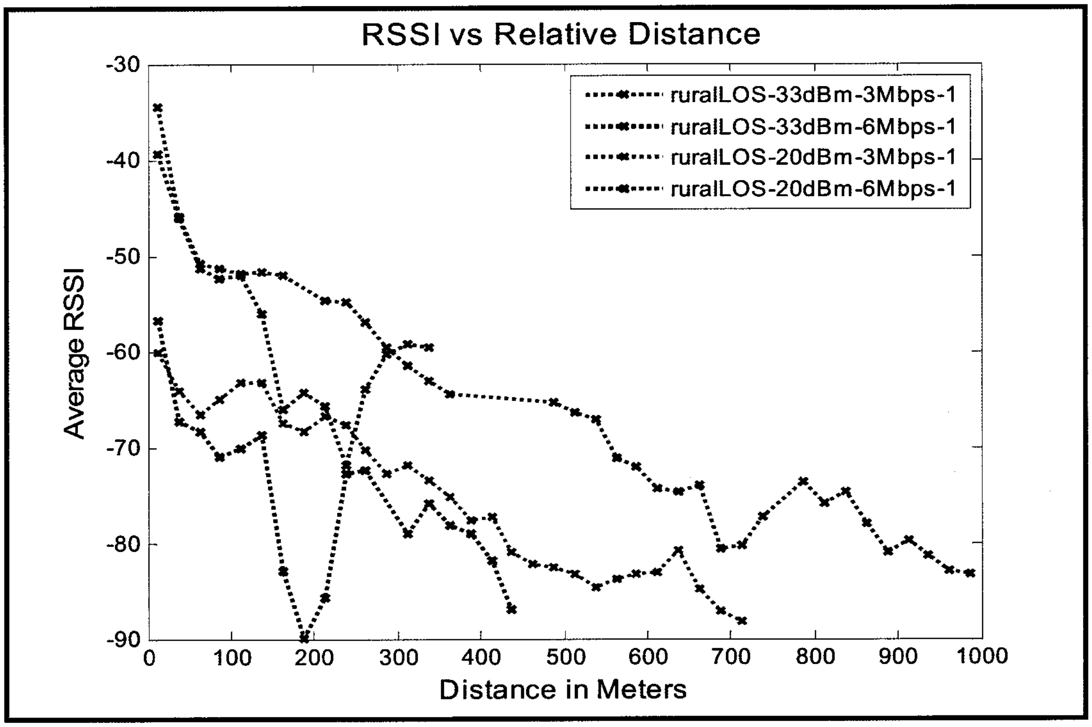


**Figure 80: Comparison of RSSI Curves in a Rural-Highway-LOS Scenario for 33 dBm and 20 dBm at 3 Mbps and 6 Mbps**

## 16.3 Observations for Rural-Highway-LOS Scenario Test

The following observations can be drawn for the Rural-Highway-LOS Scenario tests:

1. The two-lane test environment limited flexibility in varying distance between the vehicles. In some of the lower power tests, only a limited range was tested, and the tests were not terminated due to observed loss of communication. In none of the tests were PER values in excess of 20% observed.
2. 33 dBm transmission offers reliable communication ranges (PER < 10 percent) for at least 1000 meters (limit of test)
3. 20 dBm transmission offers reliable communication ranges (PER < 10 percent) for up to 700-800 meters, the actual range could be longer, but the traffic situation made it difficult to extend the V2V distance in the test
4. The 10 dBm transmission was more erratic, possibly due to curves in the highway creating NLOS conditions. The limit of reliable communication was observed to be about 150 meters.

# 17 Freeway-Shadowing Scenario Test

The Freeway–Shadowing Scenario tests with were conducted along highways US-101 and I-880 between Palo Alto, California, and Oakland, California. The same truck was used in these tests as was used in the Baseline Shadowing tests reported in Section 6. In each test, the transmitter, truck and receiver remained in the same lane. The receiver maintained a safe driving distance behind the truck; while the transmitter varied its speed to achieve a good spread of V2V distances. These tests were conducted for the various test cases outlined in Table 13.

**Table 13: Test Cases for the Freeway-Shadowing Scenario Test**

| TX Power / Data Rate | 5dBm | 10dBm | 15dBm | 20dBm | 26dBm | 33dBm |
|---|---|---|---|---|---|---|
| 3Mbps | Test 1 | Test 4 | Test 7 | Test 10 | Test 13 | Test 16 |
| 6Mbps | Test 2 | Test 5 | Test 8 | Test 11 | Test 14 | Test 17 |
| 12Mpbs | Test 3 | Test 6 | Test 9 | Test 12 | Test 15 | Test 18 |

## 17.1 Location Overview

The propagation environment was identical to that described for the Freeway LOS tests in Section 15, except for the addition of the truck to serve as a NLOS obstruction between the vehicles. Figure 81 shows a typical view of the receiver vehicle behind the truck used in these tests.